

STUDY OF WATER ABSORPTION BEHAVIOUR OF NATURAL FIBRE REINFORCED COMPOSITES

A Thesis Submitted to

National Institute of Technology, Rourkela

In partial fulfilment of the requirement for the degree of

Master of Technology
in
Mechanical Engineering

By
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Under the guidance and supervision of
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DEPARTMENT OF MECHANICAL ENGINEERING

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CERTIFICATE

This is to certify that the thesis entitled “**Investigation of mechanical properties of luffa cylindrica reinforced epoxy composite for different environmental conditions**” submitted to the National Institute of Technology, Rourkela by **Nandkishor Sharma**, Roll No. **212ME1283** for the award of the degree of **Master of Technology** in Mechanical Engineering is a record of bonafied research work carried out by him under my supervision and guidance. The results presented in this thesis has not been, to the best of my knowledge, submitted to any other University or Institute for the award of any degree or diploma.

The thesis, in my opinion, has reached the standards fulfilling the requirements for the award of the degree of Master of Technology in accordance with regulations of the Institute.

Place: Rourkela

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(NANDKISHOR SHARMA)

DECLARATION

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the award of any other degree or diploma of the university or other institute of higher learning, except where due acknowledgement has been made in the text.

(NANDKISHOR SHARMA)

ABSTRACT

Environmental perception today encourages empiricism worldwide on the learning of plant or natural fibre reinforced polymer composite and cost efficient alternative to synthetic fibre reinforced composites. The accessibility to natural fibers and simplicity in manufacturing have persuaded researchers to aim for locally existing low cost fibers and to investigate their possibility of reinforcement intensions and up to what extent they can satisfy the essential detailing of superior reinforced polymer composite intended for different application program. Natural fibre represents a superior biodegradable and renewable alternative to the most popular synthetic reinforcement, i.e. glass fibre possessing high mechanical properties and low cost. Regardless the curiosity and environmental request of natural fibers, there usage is restricted to non-bearing uses, because of its lower strength than that of synthetic fibre reinforced polymer composite. The stiffness and strength limitations of bio composites can be chased by operational arrangement by placing the fibers at particular locations to have higher strength performance. Research regarding preparation and properties of polymer matrix composite (PMC) replacing the synthetic fibre with natural fibre like Jute, Sisal, Jute, Bamboo, Pineapple, Bagasse and Kenaf were carried out. Renewable, environmental friendly, low cost, lightweight and high specific mechanical performances are the advantages of these plant fibres over the glass fibre or carbon fibre. Composites are exciting materials which are finding increasing application in transportation, aerospace, defence, communication, sporting, electronics and number of other commercial and consumer products. Composite materials have become one of the fastest growing research and development areas of Material Science because of their high potential. In current years there is swift growth in the arena of fibers, matrix, materials, processing, boundary structure, bonding and their characteristics on the final properties of composites. The technological developments in composite materials help in meeting the global industrial demand for materials with improved performance capabilities.

Keeping this in view the present work has been under taken to develop a polymer matrix composite (epoxy resin) using *Luffa Cylindrica* fibre and to study its moisture absorption behavior and mechanical properties. The composite are prepared with different volume fraction (number of layers) of *Luffa Cylindrica* fibre.

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Chapter 1

INTRODUCTION

1.1 BACKGROUND

It is a platitude that technological advances depends on fosters in the sector of materials. If sufficient materials to bear the service loads and conditions are not available then one does not have to be a skilful to realize the most advanced turbine or air-craft pattern. Whatsoever the field may be, the ultimate restriction on progression is to be governed by materials. Composite materials in this regard signify a big step in the constant accumulation of optimization in materials. Composites are mixture of two or more materials such as reinforced plastics, metals, or ceramics. The reinforcements may be in the form of fibers, particles, whiskers or lamellae and are embedded in a suitable matrix, thereby providing a material that contains the most useful properties of the constituents. High structural strength, glass fibre reinforced plastics were developed in the early 1940's and the application of reinforced plastics composites, the glass fibre provides strength and stiffness while the plastic matrix provides the temperature capabilities of the composite. Initially the glass fibres were incorporated in a polyester matrix which could withstand temperature up to 200°C. They were applied in car bodies, appliances, boats etc., because of their light weight and mitigate of production. Intricate composites parts can be made by injection moulding. Polymer matrices are usually thermosets such as epoxies. Later, resins which can withstand high temperatures, of the order of 300°C were developed such as polyamides. Other thermo setting resins include benzocyclobutene – bismaleimides. Advanced composites are manufactured by using the above polymers with reinforcements of stronger fibres such as aramid and carbon. As a result advanced composites are finding increasing applications in aircraft, automotive industry, etc. In order to reduce the manufacturing time, thermoplastics polymers such as polyether – ether ketone (PEEK) have been developed. The plastic requires only a short revelation to heat to soften the plastics, thereby allowing faster processing of the composite.

The limitations of the polymer matrix composites at high temperatures can be overcome by the use of metal matrix composites. These composites are processed by powder metallurgy methods, by penetration of the molten metal with the fibre or particulate or by mixing particulates with molten metal. Plasma spraying, vapour deposition, plasma spraying or

electro deposition followed by dispersal bonding are the other methods of fabrication. Metal matrix composites are discovering applications in defence, aerospace, automotive and electronic packaging. In addition to metal matrix composites, intermetallics such as nickel, iron, titanium and niobium aluminides matrix composites are also being actively considered for use at elevated temperatures.

The temperature range of application of metal matrix composites is lower than that of ceramic matrix composites. Ceramic matrices such as zirconia, alumina, silicon nitride, silicon carbide, mullite etc. can be reinforced with ceramic continuous fibres, whiskers or particulates. Carbon-carbon composites is a ceramic composite which can retained its strength at temperatures up to 2500⁰C and is applied as a critical component in aerospace. Adduce composites have both structural and functional applications. Adaptable composites will have the potentiality not only of load bearing but will also have an agile and flexible response to structure functional conditions. These advanced growths will increase and sensing potential of structures such as vertical tails, aircraft bulkheads, intrinsic avionics, smart skins and antenna systems. For elevated temperatures, smart metal matrix composites with fibre optic sensors in a titanium matrix composite are being boisterously considered.

The study of composites materials is a multifaceted memorandum as it is difficult for any individual to grasp the compound behaviour of many of the current composites. This field provides lot of analytical problems for experimental schedules, theoreticians for research workers and new defiance for designers. Even the technologically advanced fibre glass reinforced plastics in the 1940s require a information of ceramics, glass technology, surface science, polymers, modelling, design and analysis in order to redeem the properties, structure and purpose of the final composite product.

1.2 COMPOSITES

1.2.1 Why a composite?

Over the last three decades years composite materials, plastics and ceramics have been the ascendant developing materials. Numerous uses of composite materials have grown evenly, pervasive and dominant new markets interminably. Modern composite materials comprise a

significant amount of the engineering materials market varies from commonplace products to worldly niche applications.

Although composites have already manifested their value as weight reduction materials, the existing job is to make them cost productive. The endeavours to yield economically smart composite components have evolved in some unorthodox manufacturing techniques currently being used in the composite industries. It is vibrant, specifically for composites, that the development in manufacturing technology only is not sufficient to overcome the cost hurdle. It is important that there must be an unsegregated implementation in material processing, designing, manufacturing, tooling, quality assurance and even programmes organisation for composites to make them competitive with metals.

Further, need of composites for lighter building materials and more shock resilient structures has placed high prominence on the usage of fresh and innovative materials that not only reduces weight but also assimilates the shock and vibration by tailored microstructures. Composites at the present are largely used for rehabilitation or strengthening of preceding structures that need to be render in order to make them seismic resilient, or to restore damage due to seismic activities.

The properties of composite material can be designed by bearing in mind the structural aspects, unlike conventional materials (e.g., steel); both material and structural design operations are there in the plan of a structural component using composites. Properties of composites such as thermal expansion, stiffness etc. can be assorted frequently over a wide range of values beneath the designer control. Correct assortment of reinforcement category allows concluded product features to be customized nearly every specific engineering necessity.

1.2.2 What is a composite?

A typical composite material consists of two or more materials (bonded and mixed) on macroscopic rules which are not soluble in each other.

Normally, a composite materials are composed of reinforcement (fibers, flakes, particles and fillers) implanted in a matrix such as polymers, metals, or ceramics. The function of matrix is to hold the reinforcement to form the craved shape while the reinforcement ameliorates the whole mechanical properties of the matrix. The new

combined material possesses better strength than the each individual material in a system, when designed correctly.

As stated by Jartiz, [1] Composites are such a universal material which can provide such properties that are not possible to obtain from any distinct material. Composites possess cohesive structures brought up by physically amalgamating two or more suited materials, but different in composition and characteristics and occasionally in configuration.

Kelly [2] evidently emphasises that the composites should not be considered as just combination of two different materials. In wider sense; the amalgamation has its particular characteristic properties. In relations of strength, heat resistant or specific other advisable quality, it is far better than the components taken individually or fundamentally different from both of them.

Berghezan [3] defines as “The composites are amalgamated materials which differ from alloys by the fact that the individual components in composites preserve their characteristics but are combined in such a way so as to take advantage of their features only and not of their limitations”, in order to obtain a much better material.

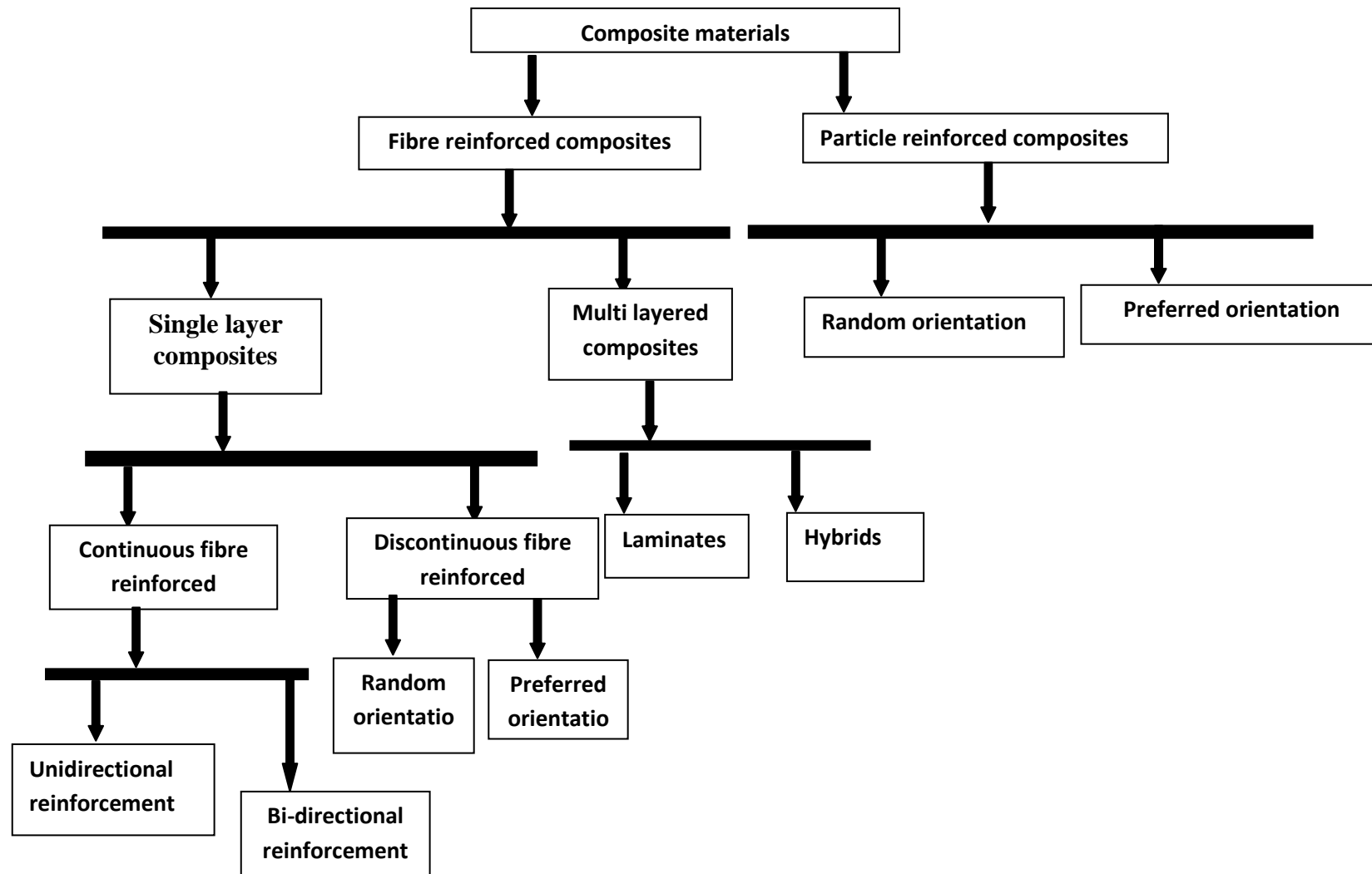
Van Suchetclan [4] describes composite materials as diverse materials which consist of two or more solid states that are in constricted interaction with each other. He also stated that composites can be also contemplated as homogeneous material on a microscopic level in a way that whichever part of it is separated will have the physical property same as the composite.

1.2.3 Classification of Composites

Composite materials perhaps categorized in distinct ways [5]. Arrangement based on the geometry of a characteristic unit of reinforcement is suitable since it is the geometry of the reinforcement which is liable for the mechanical properties and better presentation of the composites. The classification is presented in Table1.1. The two broad classes of composites are:

- (i) Fibrous composites
- (ii) Particulate composites

Table-1.1 Classification of composite



1.2.3.1 Particulate Composites

The name only specifies, that the reinforcement possesses particle nature. It may be cubic, spherical, tetragonal, or of any regular or irregular shape, but it is approximately equiaxial. In common, particulates are not much productive in enhancing fracture resistance but it increases the stiffness of the composite to a restricted amount. Particle fillers are largely used to upgrade the properties of matrix materials such as to improve the electrical and thermal conductivity, to improve performance at high temperatures, abrasion resistance, decrease friction, improve wear, increase surface hardness, increase machinability and lessens shrinkage.

1.2.3.2 Fibrous composites

Fibres are well known for its length and cross-section ratio i.e. their length is much greater than that of cross-sectional dimensions. The reinforcement dimension plays a significant role in governing its potentiality of contributing properties to the composites. Since reinforcement possessing a long dimension depresses the growth of developing cracks usual to the reinforcement that might result to wreck, especially with brittle matrices as fibers are very effectual in enhancing the fracture resistance of the matrix.

1.3 COMPONENTS OF A COMPOSITE MATERIAL

In its most basic form a composite is the element which comprises of two or more elements (at least two elements) that are bonded together to produce a different material which produces enhanced properties that are better and different to the properties of the individual elements. Usually composites comprises of reinforcement and a matrix, incorporated mainly to raise the stiffness and the strength of the matrix.

1.3.1 Role of matrix in a composite

Numerous materials when are in a fibrous form display very high strength but in order to attain these properties the fibers must be joined by an acceptable matrix. The role of matrix is to separate the fibers from each other in order to avert abrasion and development of fresh surface flaws and to stick the fibers in place by acting as a bridge. A quality matrix must possess the capability to transfer the load onto the fibers, deform easily under applied load.

In case of laminates [6] the nature of bonding forces indicates that upon initial loading there is a proneness for the adhesive bond between the matrix and reinforcement to be failed. The frictional forces between them portrayal for the high strength properties of the laminates.

1.3.2 Material used as matrices in composites

1.3.2.1 Bulk-Phases

- (a) Metal Matrices
- (b) Polymer Matrices
- (c) Ceramic Matrices

1.3.2.2 Reinforcement

In a composite material the purpose of the reinforcement is basically to increase the mechanical properties of the neat resin structure. The properties of the composite are affected differently by different fibers used in it as these fibers have different properties. For various applications, the fibres are required to be organised into the structure of sheet, known as a fabric, in order to make handling possible.

1.3.2.3 Interface

The important feature of interface is that its properties are not rendered by any component in the system on isolation. It is a bounding zone at which disturbances occurs, it can be mechanical, chemical, physical etc. It is required that fibre must be wetted by the matrix material and in order to improve this wettability coupling agents are used frequently. Increase in the interface surface area is only possible when the fibre is well 'wetted'. The applied load must be effectually transferred to the fibers from the matrix through the interface to get the advisable properties and this concludes that the interface should be large and the fibers and matrix must be joined strongly.

1.4 TYPES OF COMPOSITE MATERIALS

The composite materials are classified into the following categories as shown in Figure-1.1 (a - e).

1.4.1 Fibre-reinforced composites

Because of intrinsic high specific strength and stiffness these composites are universally used in numerous industrial applications. These composites are acquiring high potential in tribological applications also as they possess brilliant structural presentation. Fiber reinforced composites materials comprises of fiber of high strength in or bonded to a matrix with discrete interfaces between them [4, 5]. In this form physical and chemical identities are retained by both fibres and matrix. Yet they produce an amalgamation of properties which is difficult to achieve with either of the composite constituents individually. In general, the role of fibers is to carry load, whereas the role of matrix is to keeps them in the crave position and alignment [5, 6]. Fibrous composite can be further classified into two groups: continuous (long) fiber composite and discontinuous (short) fiber composite.

1.4.1.1 Continuous or long fiber composite

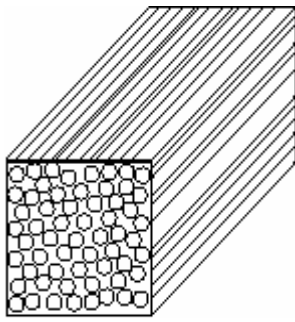
Geometrically, a continuous fibre is distinguished as it possesses a high length to diameter ratio. It also comprises of reinforcement matrix by a disseminate phase in the type of continuous fibre. These are basically tougher and stiffer when compared to matrix i.e. bulk phase material. Based on the manner in which fibers are stuffed within the matrix, it is again subdivided in to two categories: (a) unidirectional reinforcement and (b) bidirectional reinforcement. In unidirectional reinforcement, the fibers are aligned in one direction only where as in bidirectional reinforcement the fibers are aligned in two directions either at some desired angle (angle-ply) or at right angle to one another (cross-ply). When fibers are continuous and large, they transmit certain degree of anisotropy to the properties of the composites especially when they are oriented. Multi-axially oriented continuous fibre composites are also exhibit near isotropic properties.

1.4.1.2 Discontinuous or short fiber composite

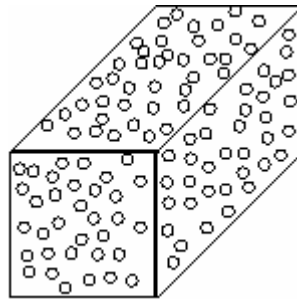
Short-fiber reinforced composites comprises of a reinforced matrix by a distributed phase in the type of discontinuous fibers which are having, length $< 100 \times \text{diameter}$. The low cost, proficiency of fabricating intricate parts, and isotropic nature are sufficient to make the short fiber composites the material of selection for large-scale production. Accordingly, the short-fiber reinforced composites have profitably established its place in lightly loaded component production. Furthermore the discontinuous fiber reinforced composite divided into: (a) biased or preferred oriented fiber composite and (b) random oriented fiber composite. In the prior, the fibers are oriented in pre-decided directions, whereas in the later type, fibers remain randomly. The alignment of short fibers can be done by scattering of fiber on to given plane or inclusion of matrix in liquid or solid state before or after the fiber displacement.

1.4.2 Laminate Composites

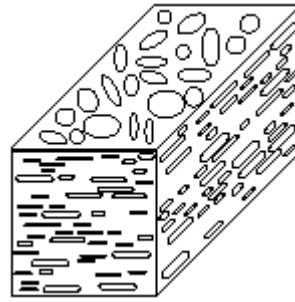
Laminate Composites consists layers of material held together by matrix. Mainly, these layers are organized alternatively in order to provide a better bonding between the reinforcement and the matrix. According to the end use of the composite these laminates can have uni- directional or bi-directional orientation of the fiber reinforcement. The different types of composite laminates are angle-ply, unidirectional, symmetric laminates and cross-ply. A blended laminate can also be fabricated by the use of alternate constituent materials or of the same material with alternate reinforcing design. In most of the applications of laminate composites, man-made fibers are used because of their good amalgamation of physico-mechanical and thermal behaviour.



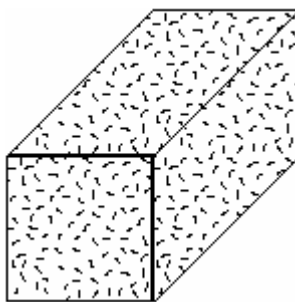
(a) Continuous fiber composite



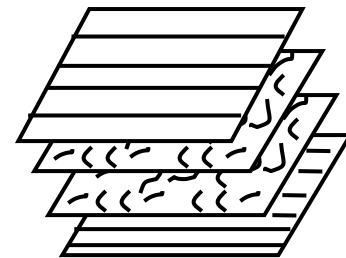
(b) Particulate composites



(c) Flake composites



(d) Random fiber (short fiber) Composite



(e) Laminate Composite

Figure-1.1 (a-e) Different types of Composite

1.5 NATURAL FIBER COMPOSITES: Initiative in Product Development

The cost effective option to synthetic fibre reinforced composites and the interesting studies of plant or natural fibre inspires the researchers to make advances in the field of composites. Ease in access and built-up simplicity of natural fibre have convinced these researchers to try natural fibres which are available locally and to study their practicability of reinforcement motives. These are also studied to have the information that up to what limit they can fulfil the desired specifications and properties for various uses. Natural fibre appears as a good renewable and biodegradable substitute to most of the synthetic fibre such as glass fibre.

Vegetables, animal, mineral fibers etc. fall under the area of natural fibre. Generally it is referred as wood and agro based fibre, leaf, stem and seed fibers in the composite engineering. A natural fibre frequently contributes to the structural presentation of plant and

they can deliver substantial reinforcement, when used in the production of plastics composites.

Is curtailed to non-bearing applications because of their bring down strength compared to synthetic fibre reinforced polymer complex in malice of the interest and environmental appeal of natural fibers. By the sense of positioning the fibers in particular locations for maximum strength presentation, the limitations in stiffness and strength of bio composites can be succeeded.

Accordingly vast studies on construction and properties of polymer matrix composite (PMC) substituting the synthetic fibre with natural fibre like Jute, Pineapple, Sisal, Kenaf, Bamboo, luffa cylindrica, ipomea carnea and Bagasse were executed [7-12]. Above natural fibers have numerous advantages over the glass fibre or carbon fibre such as renewable, low cost, lightweight, high specific mechanical performance.

1.5.1 Applications

- 1. Automobile industry:** For inner and outer parts fibre reinforced plastics are used. These are used in industries because of their advantages over the glass fibre reinforced composites such as cheaper, environment friendly, etc. By these fibers cars according to End-of-Life directive can be developed as the resulting products from these composites can be re-used and do not have to be land filled unlike glass fibre. Because of their softness and non-harsh behaviour unlike glass fibers they are used in interior automotive uses and are having advantages of not injuring the passengers.
- 2. Packaging industry:** In these industries these are used for light weight pallets. Weight reduction is the chief reason for using composite material in place of wood, which saves fuel during transportation.
- 3. Consumer products:** Natural fibre can be used for any injection moulded product. Reduction of plastic use, flame retardancy and re-use. Examples are household appliances like cell phones, refrigerators and computers. They are less vulnerable to fire due to the fibre structure of composite. Also the high fibre loads results in major material cost reduction.

4. **Building and construction industry:** In these they are used for roofings and instance profiles. Cost reduction, re-use and flame retardancy are the advantages.

1.5.2 *Luffa cylindrica* as a natural fiber

Numbers of potential natural resources are there, which India has in abundance. Most of which comes from the forest and agriculture.



Fig 1.2 (a)



Fig 1.2 (b)



Fig 1.2 (c)

Fig 1.2 (d)

Fig. 1.2 The *Luffa cylindrica* plant (a), the inner fiber core (b) and the outer core open as a mat (c, d).

Luffa cylindrica, locally called as ‘Sponge-gourds’ is that natural resource whose capability as fiber reinforcement in polymer composite has not been explored to date. The fibrous cords are liable in a multidirectional array resulting in a natural mat in ligneous netting system possess by ‘Sponge gourds’. It comprises 62% cellulose, 20% hemicellulose and 11.2% lignin [1]. The sponge-gourd (*Luffa Cylindrica*) plant with fruit which belongs to the curcubitacea family is shown in Fig. 1.1(a).

The main objective of this project is to prepare a PMC using luffa fiber as reinforcement and epoxy as matrix material and to study its moisture absorption characteristics under different environmental conditions and then to find its mechanical properties i.e.; tensile and flexural strength. Out of the available manufacturing techniques, we have chosen hand-lay-up method to construct the composite. Then the composites were manufactured by varying the no. of layers of fiber i.e.; single, double and triple layers composite using these techniques. The surface of fracture and worn out samples have been studied using Scanning Electron Microscope (SEM) to have an idea about the fracture behaviour of the composite.

In the 2nd chapter, detailed discussion on reinforcement material, outline of fabrication processes and effort related to current investigation available in literature are presented.

In the 3rd chapter, the effect of environment on mechanical properties of both treated and untreated fiber reinforced composite along with moisture absorption characteristics have been presented.

Chapter 2

LITERATURE SURVEY

2.1 NATURAL FIBERS: Source and Classification

Growing environmental awareness has activated the researchers worldwide to enhance and utilize materials that are companionable with the environment. In the procedure natural fibers have become suitable options to traditional synthetic or manmade fibers and have the prospective to be used in cheaper, more sustainable and more environment friendly composite materials. Natural organic fibers can be obtained from either animal or plant sources. Most of the useful natural textile fibers are obtained from plant, with the anomaly of wool and silk. All plant fibers comprises of cellulose, whereas protein act as a chief content of fibers of animal origin. Hence, the natural fibers are categorized on the basis of their origin, whereas the plant fibers can be further classified on the basis of plant parts from which the parts are originated. An overview of natural fibers is showed in Figure-2.1 [13].

Normally, plant or vegetable fibers are cast to reinforce polymer matrices and a categorization of vegetable fibers is given in Figure-2.1 [14]. Plant fibers are a renewable resource and have the capability to be recycled. The plant fibers leave slight residue if they are burned for disposal, returning less carbon dioxide (CO₂) to the atmosphere than is separated during the plant's growth.

The chief driver for switching natural fibers for glass is that they can be grown with lesser cost than glass. The price of glass fiber is around Rs. 300.0/- per kg and has a density of 2.5 gm/cc. On the other hand, natural fiber costs Rs. 15.0/- to 25.0/- per kg and has a density of 1.2-1.5 gm/cc. As can be seen from Table-2.1 [13], although the modulus is of the same order of magnitude, the tensile strength of natural fibre is considerably lower than the glass fibers. On the other hand, when the specific modulus of natural fibers is measured, the natural fibers show values that are similar to or even better than glass fibers. Material cost savings, suitable to the use of natural fibers and high fiber filling levels, coupled with the benefit of being non-abrasive to the mixing and moulding tools make natural fibers a thrilling outlook. These reimbursement mean natural fibers could be used in many applications, including building, automotive, household appliances, and several other applications.

Table-2.1 Properties of glass and natural fibers

Mechanical Properties	Fibers						
	E-glass	Hemp	Flax	Jute	Sisal	Coir	Ramie
Density (gm/cc)	2.25	1.48	1.4	1.46	1.33	1.25	1.5
Tensile Strength (MPa)	2400	550-900	800-1500	400-800	600-700	220	500
Young's Modulus (MPa)	73	70	60-80	10-30	38	6	44
Specific Modulus (MPa)	29	-	26-46	7-21	29	5	2
Failure Strain (%)	3	1.6	1.2-1.6	1.8	2-3	15-25	2
Moisture Absorption (%)	-	8	7	12	11	10	12-17

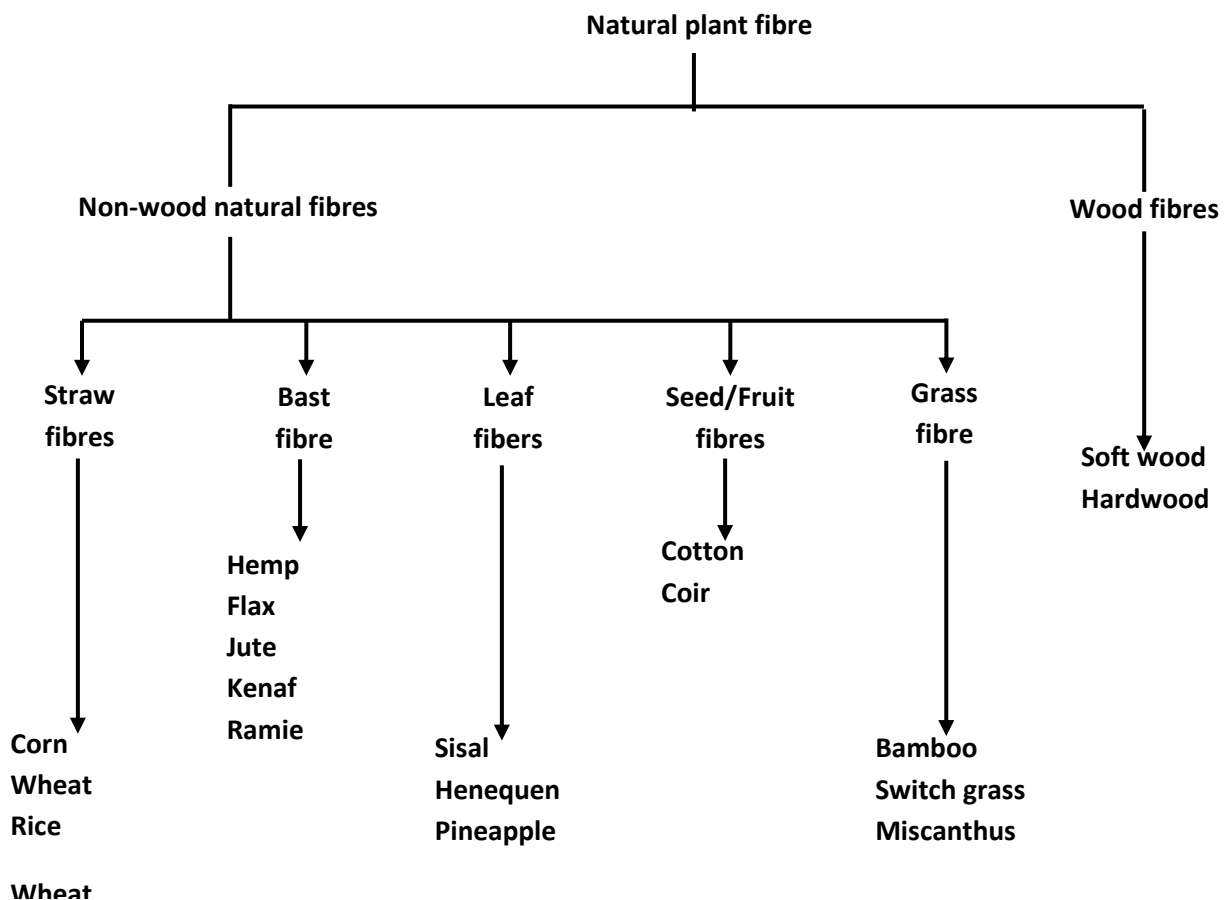


Figure-2.1 Classification of natural fiber that can be used as reinforcements.

2.2 CHEMICAL COMPOSITION OF NATURAL FIBERS

The component of any natural fiber differs with variety, area of production and origin, maturation of plant. The major component of a fully developed natural fiber cell walls are cellulose, hemicellulose, lignin and pectin. These –OH including polymers are distributed all the way through the fibre wall [15].

2.2.1 Cellulose

The long thin crystalline micro-fibrils in the secondary cell wall are prepared of cellulose. It is the reinforcing material and is in charge for better mechanical strength of fibers. Chemically, cellulose is explained as a highly crystalline section alternating with regions of non-crystalline or amorphous cellulose [16, 17].

The glucose monomers in cellulose form hydrogen bonds both inside its own chain (intramolecular) forming fibrils and with neighbouring chains (intermolecular), creating micro-fibrils. These hydrogen bonds lead to development of a linear crystalline structure with high rigidity and strength. The amorphous cellulose sections have a lower frequency of intermolecular hydrogen bonding, thus revealing reactive intermolecular -OH groups to be bonded with water molecules. Amorphous cellulose have tendency to bond with water hence they are considered as hydrophilic in nature. On the contrary, crystalline cellulose possess very low accessible intermolecular –OH and thus it possess far smaller amount hydrophilicity than the amorphous cellulose. Crystalline micro-fibrils have accessible –OH available on the surface of the structure and also have closely filled cellulose chains in the fibrils. Only extremely strong acids and alkalis may go through and transform the crystalline lattice of cellulose.

2.2.2 Hemicelluloses

Hemicelluloses vary from cellulose in three dissimilar ways.

1. In contrast with cellulose (including 1,4- β -D-glucopyranose units only) they have some assorted sugar units.
2. They reveal a considerable degree of chain branching, while cellulose is a linear polymer.

3. The standard of polymerization of local cellulose is ten to hundred times greater than the hemicelluloses.

The element of hemicelluloses differs from plant to plant unlike cellulose. It includes substituent like -COCH₃ groups and glucuronic acid.

Chiefly the acid residue close to hemicelluloses makes it highly hydrophilic and raises the fiber water uptake, which increases the danger of microbiological fiber deprivation. It has been found that at lower temperatures hemicelluloses thermally degrade more (150-180°C) than cellulose (200-230°C) [18].

2.2.3 Lignin

Collectively with cellulose, it is the superabundant and significant polymeric organic substance in the world of plant. For trees of 100 meters height to stay upright lignin plays a major role as it multiplies the compression strength of plant fibers by sticking the fibers collectively to form a stiff structure. Lignin is basically a chaotic, polyaromatic, and cross-linked polymer emerging from the free radical polymerizations of two or three monomers structurally associated to phenyl-propane [19]. The lignin matrix is consequently similar to a thermoset polymer in conservative polymer terminology. The disbanding of lignin using chemicals aids fiber separation. When reveal to ultraviolet light, lignin undergoes photochemical deprivation. The lignin seems to perform like a matrix material contained by the fibers, making stress transfer on a micro-fibril scale and single fiber scale achievable.

2.2.4 Pectin

Pectin, otherwise called pectic polysaccharides, is rich in galacturonic acid. A few different polysaccharides have been distinguished and described inside the pectic gathering. Homogalacturonans are direct chains of α -(1-4)-joined D-galacturonic acid.

Pectin is a confounded stretched structure of acidic structural polysaccharides, established in fruits and bast fibers. Of all the compound in plant fibres pectin is the most hydrophilic in nature as it contains carboxylic acid groups and is basically debased by defibration with organisms [16]. Pectin together with hemicelluloses and lignin existing in natural fibres can be hydrolysed at elevated temperatures.

Table- 2.2 Comparison between Natural Fibre and Glass Fibre

	Natural Fibre	Glass Fibre
Density	Low	Twice that of Natural fibre
Cost	Low	Low, but higher than Natural fibre
Renewability	Yes	No
Recyclability	Yes	No
Energy Consumption	Low	High
Distribution	Wide	Wide
CO ₂ neutral	Yes	No
Abrasion to Machining	No	Yes
Health risk when inhaled	No	Yes
Disposal	Biodegradable	Not Biodegradable

2.3 MATRIX MATERIAL

High strength properties are shown by various materials only when they are in fibrous form and these properties are attained if the fibre is bonded by an appropriate matrix. Matrix segregates the fibers from each other so as to avoid abrasion and establishment of fresh surface defect and behave as a link to grip the fibres in a particular position. Under applied load, matrix tends to possess the capability to deform quite easily, uniformly distribute concentrated stress and transfers the load to the fibers effectively but in order to get these the matrix should be of good quality.

A study of the nature of bonding forces in laminates [20] specifies that upon initial loading there is an affinity for the adhesive bond into them to report for the high strength properties of the of the laminates.

In order to transfer the load to the fibers through matrix and to guard them from handling and environments the polymer matrix should sticks the fibers together. Polymer or resin systems are used to manufacture advanced Polymer Matrix Composites (PMCs) is of two primary types, thermosets and thermoplastics.

2.3.1 Thermosets

Much of the initial work used thermosetting resins as matrix material for composite construction. Products like tufnol which is shaped using cotton fibres and epoxy resin, have been available for some time, possessing good stiffness and strength [21]. In the past few years there has been transformed interest in these products for use in automotive applications. To attain reinforcing consequences in composites it is essential to have decent adhesion across the resins and fiber. Epoxy and phenolic thermosetting resins are well-known to be capable to form covalent cross-links with plant cell walls along -OH groups. Production of composite can be achieved by means of low viscosity epoxy and phenolic resins that cure at room temperature. In accumulation epoxy resin does not yield volatile products throughout curing which is most advisable in construction of void free composites. Although epoxy resins are comparatively more expensive than polyester, they possess high potential for the development of added value plant fiber composites, whereas long fibres at a high content are mandatory.

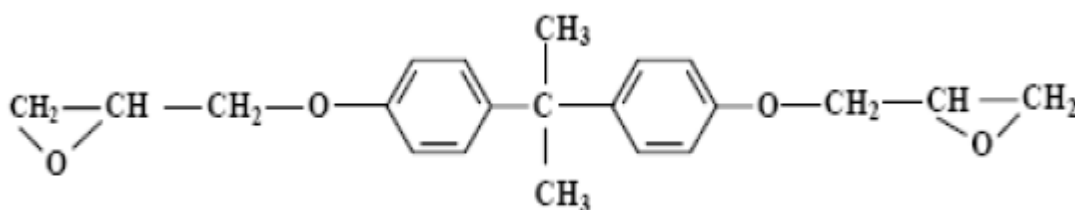


Figure-2.2 Chemical structure of DGEBA

For curing agents of epoxy resins primary and secondary amines are mainly used. On the whole, reaction rate of an amine with an epoxide is dominated by the steric encumbrance and the electron donating groups that exists in the amine.

The merits of epoxy resins are low polymerisation shrinkages unlike polyesters during cure, excellent resistance to chemicals and solvents, good mechanical strength, and excellent adhesion to fibres. The epoxy molecule consist of two ring groups at its centre, that have the capability to absorb both thermal and mechanical stresses better than the linear groups, giving epoxy resin very good strength, toughness, stiffness and heat resistance.

The main demerits of the epoxy resins are that they need long curing times and, for the most part, their mould discharge qualities are poor. The epoxy resins are categorized by

high adhesive strengths. After reviewing the stimulating literature accessible on the natural fiber composite hard work are put to recognise the basic needs of the emerging composite industry. The decisions drawn from this is that, the achievement of merging vegetable natural fibers with polymer matrices results in the improvement of mechanical properties of the composite associated with the matrix material. These fillers are cheap and non-toxic and can be acquire from renewable source and are effortlessly recyclable. Furthermore in spite of their low strength, they may results into composite possessing high specific strength due to their low density.

Thus significance of this work is to prepare polymer matrix composites (PMCs) using Luff Cylindrica fiber as reinforcement material. To increase the interfacial strength among the fibre and the matrix, the surface alteration of the fibre has to be done by chemical treatment. The composite is then being subjected to different environmental conditions like saline and distil condition. The mechanical properties of the composite will be estimated along with moisture absorption characteristics.

Chapter 3

MECHANICAL CHARACTERIZATION OF LUFFA CYLINDRICA FIBRE EPOXY COMPOSITE

3.1 INTRODUCTION

In common natural fibers are absorptive in nature and they take up or liberate moisture relying on to the environmental conditions. For high moisture absorption rate amorphous cellulose and hemicellulose present in the fibre are the main reasons, as they possess innumerable easily available -OH groups which provide an increased level of hydrophilic property to the fibre. The high moisture absorption of the fiber happens due to hydrogen bonding of water molecules to the -OH groups in the fiber cell wall. This guides to a moisture growth in the fibre cell wall (fibre swelling) and also in the fibre-matrix border. This in turn becomes liable for variations in the dimensions of cellulose-based composites, mainly in the thickness and the linear expansion because of reversible and irreversible swelling of the composites. In order to solve this problem, chemical treatment has been taken into account as a good method to reduce the -OH group in the fibers. Different chemical treatments such as alkali treatment, acrylation, benzylation, isocyanate treatment, acetone treatment, acetylation, silane treatment, permanganate treatment etc. are reported by many researchers [22, 23].

The moisture uptake of composites comprising natural fibers has some unfavourable causes on their properties and hence disturbs their long-term presentation. In view of the sternness of moisture absorption and its consequences on composite properties, a number of efforts have already been made by several researchers to address this issue.

Jena et al. [24] studied the water absorption behaviour of bamboo-epoxy composite filled with cenosphere. Water absorption of bamboo fibre increases with time of immersion, attaining a saturation point after which it remains constant. She observed that the saturation point was different for two different environmental conditions. For distilled water it was 216 h whereas for saline water it was 168 h.

Joseph et al. [25] investigated the environmental effects on sisal fibre reinforced PP composites. Absorption of water was found to be increased with the fibre content and then settled off at longer period of time. In order to overcome this problem the fibres were treated

chemically and the chemically treated fibres showed a decrease in water absorption because of the enhanced interfacial bonding. As the temperature stimulates the diffusion procedure, it was found that the water absorption of the composite increases with the temperature. Plasticization effect of water was the reason to decrease the tensile properties of the composites.

Yuan et al. [26] experimented the plasma treatment of sisal fibers and its possessions on tensile strength and interfacial bonding. They recommended that cleaned and chemically customized fiber surface improves the interfacial adhesion among the fibre and matrix. The rate of moisture absorption in bio-composite was reduced by the strong intermolecular bonding among fiber and matrix.

Stamboulis et al. [27] reported that the swelling and moisture absorption of the treated flax fibre polypropylene composites is lower than the untreated flax fibers composites. The result shows that the absorption for the treated fibre is approximately 30% lower than the untreated fibre composites.

Thomas et al. [28], while experimenting water absorption characteristics of sisal fiber polyester composites established that the diffusion coefficient decreases with chemical treatment of fiber. In addition to this the chemical treatment also reduces water absorption capacity of the composite. They also showed that the composite with benzoyl-chloride treated sisal fiber composite exhibited lower water absorption capacity.

Satyanarayana *et al.* [29] have investigated on lignocellulosic fibers of Brazil. They reported the accessibility to some of the Brazilian lignocellulosic fibers, extraction methods, properties, their market and their applications. International trends in the study of lignocellulosic fibers tells that, these fibers have dormant use in automotive applications; they can be perfect competitors for the non-renewable, costly petroleum-based synthetic fibers in composite materials, mostly in the automotive industry and counting building sectors.

Andrzej *et al.* [30] have studied the impact of the type of reinforcing fibre, fibre and void content on the mechanical properties of composites. Increase in the shear modulus and impact strength was influenced by increasing the content of the fibre. There is decrease in impact strength and shear modulus due to increase in micro void content.

Verma *et al.* [31] have examined the usage of bagasse fiber and its current calibre of research. Many citations to the latest work on processing, application and properties have been quoted in this assessment. The main aim of their study was to employ the benefits provided by renewable resources for the development of composite materials based on bagasse fibers. They determined that the natural fibre composites can be more suitable for technical applications such as automotive interior parts when they are hybrid with certain quantity of synthetic fibre.

Herrera-Franco *et al.* [32] have investigated the mechanical performance of high density polyethylene (HDPE), strengthened with continuous henequen fibers. They established that the strength and toughness of the composite depends on the quantity of silane settled down on the fiber and with the surface alteration there is no enhancement in the elastic modulus of the composite.

Oboh *et al.* [33] have reported the potentialities of *Luffa cylindrica* crop that is virtually found around the world. Regions such as medicine, agriculture, science, biotechnology and engineering were discussed. Recent major improvements and discoveries were considered. They conclude that in the context of the morphosynthesis, the capability of replication of the luffa sponge unties the chances of the use of biodiversity in obtaining new materials. This emerging cash crop will expand the economies of many nations in the nearest future because of its numerous potentials.

Yoldas Seki *et al.* [34] carried out report of *Luffa cylindrica* by scanning electron microscopy (SEM) analysis. The contents of hemicellulose, lignin and cellulose in *Luffa cylindrica* were determined. They subject luffa cylindrica-reinforced polyester composite to water aging in a steam of seawater containing 5% NaCl for 170 hrs at 50⁰C. They found that flexural strength, tensile strength, tensile elongation and interlaminar shear strength at break values was decreased by 28%, 24%, 45%, and 31%, respectively, after the process of aging.

Msahli *et al.* [35] have reported the influence of fiber weight ratio ,reinforcement structure and chemical modification on the flexural proprieties of Luffa-polyester composites. It resorts that acetylating and cyanoethylating improve the flexural strength and the flexural modulus. They established that the fiber weight ratio influenced the flexural properties of composites. Positively, a maximum value of strength and strain is observed over a 10% fiber weight ratio. They examined the uses of various reinforcement structures.

3.2 CHEMICAL MODIFICATION OF FIBER

Utilizing natural fibers as reinforcement in the organization of plastic composites has improved intensely in recent years. For a well-developed composite using natural fibre as reinforcement the understanding of surface adhesive bonding of fibre and the chemical composition is essential. Interfacial bonding between fibers and the resin needs to be good as it plays a significant role in enhancing the mechanical properties of the composites. Understanding the importance of chemically modified fibers, numerous authors have started studying treatment of fibers in order to develop the bonding with resin matrix. The quantity of individual material in a composite and the nature of interfacial region between matrix and reinforcement decides the mechanical properties of the composites.

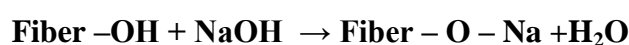
Absence of good interfacial adhesion makes the usage of cellular fiber composites less attractive. Frequently, due to water absorbing nature of natural fibre the interfacial properties between the fiber and polymer matrix tends to be low, which decreases its potential of being used as reinforcing agents. Hence chemical alterations are taken into account to enhance the interface of fibers. There are several chemical treatments that exist for the fibre surface modification. Chemical treatment comprising alkali, silane, acetylation, benzylation, acrylation, isocyanates, maleated coupling agents, permanganate treatment are discussed in details in.

The main reason for performing chemical alterations on natural fibres is to improve the adhesion between fibre surface and the polymer matrix by altering the fibre surface and the fibre strength. It also helps in enhancing the mechanical properties by decreasing the water absorption capability of the fibre. Out of the available treatments, for the present case to have a decent bonding between the fibre and the matrix *Luffa Cylindrica* fibre have been treated with alkali. The subsequent section will elaborate separately the treatment of the fibre surface by alkali methods, study of mechanical properties of both treated and untreated fibre reinforced polymer composite followed by studying environmental effects on mechanical performance of the composite along with moisture absorption characteristics.

3.2.1 Method of Chemical Modification

3.2.1.1 Alkaline Treatment

When it comes to reinforce thermoplastics and thermosets, alkaline treatment is one of the mostly used treatments. In the modification done by the alkaline treatment the disruption of hydrogen bonding in the network structure takes place resulting in increased surface roughness. By using this treatment, certain amount of lignin, wax and oils covering the outer surface wall of the fibre was removed, depolymerizes cellulose and depicts the short length crystallites [36]. Addition of aqueous sodium hydroxide (NaOH) to natural fibre stimulates the ionization of the -OH group to the alkoxide.

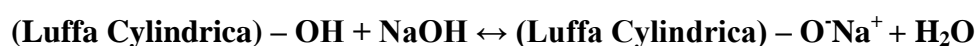


Alkaline treatment has two effects on the fibre:

- 1) It increases surface roughness by the disruption of hydrogen bonding resulting in better mechanical linking, and
- 2) It increases the number of possible reactions sites by increasing the amount of cellulose exposed on the fibre surface.

Subsequently, this treatment has a lasting effect on the mechanical behaviour of flax fibre, especially on the strength and stiffness of the fibre.

For performing this treatment, Firstly the *Luffa Cylindrica* fibre were kept in a solution containing 5%NaOH at room temperature maintaining a liquor ration of 15:1 for 4hrs. Secondly, the fibers were washed many times with water in order to remove the NaOH sticking to the fibre surface followed by neutralizing with dilute acetic acid and washed with distilled water, so that pH of 7 was maintained. Lastly, the fibers were dried at room temperature for 48hrs followed by oven drying for 6hrs at 100°C. The alkali reaction between *Luffa Cylindrica* fibre and NaOH is as follows:



3.3 COMPOSITE FABRICATION

For preparation of composite the following materials have been used;

1. Luffa Cylindrica fiber
2. Epoxy
3. Hardener

3.3.1 Preparation of Luffa Cylindrica Fiber Mats

Dried Luffa Cylindrica was collected locally. These fibres were then treated with water for 24 hrs in order to remove wax, lignin and oil from the external surface of luffa fibre and then dried at room temperature. After these the fibres were cut with appropriate dimensions (150×140 mm) and then these fibres were kept between two wooden boards followed by pressing it into the bench vice to straighten the fibres.

3.3.2 Epoxy Resin

The epoxy resin used in this examination is Araldite LY-556 which chemically belongs to epoxide family. Its common name is Bisphenol-A-Diglycidyl-Ether. The hardener with IUPAC name NNO-bis (2aminoethylethane-1,2diamin) has been used with the epoxy designated as HY 951.

3.3.3 Composite preparation

Initially, wooden moulds with dimensions of 140 x 120 × 10 mm³ were prepared for the fabrication. For different number a layer of fibre, epoxy resin and hardener (ratio of 10:1 by weight) with a calculated amount was mixed thoroughly in a glass jar. Figure 3.1(a) illustrates the mould used to construct the composite. Mould release sheet was put over the glass plate and a mould release spray was sprayed over the inner surface of the mould for quick and easy removal of composite. After keeping the mould on a ply board a thin layer of the mixture was poured. Then the fiber lamina was distributed on the mixture. Then again resin was applied over the fiber laminate and the procedure was repeated to get the desired thickness. The remaining mixture was then poured into the mould. Precaution was taken to prevent the air bubbles formation. Then from the top pressure was applied and the mould was kept at room temperature for 72 hrs. During application of pressure some amount of mixture

of epoxy and hardener squeezes out. Care has been taken to consider this loss during manufacturing of composite sheets. After 72 hrs the samples were taken out of the mould. Figure 3.2 (a, b) shows the photograph of the composite specimen cut for further experimentation.



Figure- 3.1 Mould used for fabrication of the composite



Figure-3.2 (a) Flexural test samples



Figure-3.2 (b) Tensile test samples

3.4. STUDY OF ENVIRONMENTAL EFFECT

To study the effect of environmental conditions on performance of Luffa Cylindrica fiber epoxy composite, the composite sample with both untreated and chemically treated fibers were subjected to various environments such as:

- (a) Saline treatment
- (b) Distil treatment

3.4.1 Moisture absorption test

Moisture absorption and thickness swelling tests were conducted in accordance with ASTM D570-98. Four specimens for different layers (Single, Double and Triple layers) were cut with dimensions of 140 x 15mm (length x width) and the experiment was performed using test samples. The specimens prior to testing were dried in an oven at 80⁰ C and then were allowed to cool to room temperature and kept in a desiccator. The weight of the samples were taken before subjected to steam, saline water and distil water environments. After expose for 12 hr, the specimens were taken out from the moist environment and all surface moisture was removed with a clean dry cloth or tissue paper. The specimens were reweighed to the nearest 0.001 mg within 1 min. of removing them from the environment chamber. The specimens were weighed regularly from 12-156 hrs with a gap of 12hrs of exposure. The moisture absorption was calculated by the weight difference. The percentage weight gain of the samples was measured at different time intervals by using the following equation:

$$\%M_t = \frac{(W_t - W_o) \times 100}{W_o} \quad (3.1)$$

Where ‘ W_o ’ and ‘ W_t ’ denote the oven-dry weight and weight after time ‘ t ’, respectively. Equilibrium Moisture Content (EMC) of the sample is the moisture content when the periodic weight change of the sample was less than 0.1% and thus the equilibrium state was assumed to be reached.

The thickness swelling (TS) was determined by using the following equation:

$$TS(t) = \frac{H_t - H_o}{H_o} \times 100 \quad (3.2)$$

Where, ‘ H_t ’ and ‘ H_o ’ are the composite thickness after and before the water immersion respectively.

3.4.2 Mechanical testing of sample

3.4.2.1 Tensile test

The tensile test is generally performed on flat specimens. The most commonly used specimen geometries are dog-bone and the straight side type with end tabs. The specimen used in present case is shown in fig 3.3 (a). The tensile tests were conducted according to ASTM D 3039-76 standard on a computerized Universal Testing Machine INSTRON H10KS. The span length of the specimen was 42 mm. the tests were performed with constant strain rate of 2 mm/min.



Figure-3.4 (a) UTM machine sample unloaded for tensile testing



Figure 3.4 (b) UTM machine sample loaded for tensile testing

3.4.2.2 Flexural test

Three point bend test was carried out in an UTM machine in accordance with ASTM D790-03 to measure the flexural strength of the composites. The loading arrangement for the specimen and the photograph of the machine used are shown in figure 3.5. All the specimens (composites) were of rectangular shape having length varied from 100-125 mm, breadth of 100-110 mm and thickness of 4-8 mm. A span of 70 mm was employed maintaining a cross head speed of 0.5mm/min.

The flexural strength of composites was found out using the following equation

$$\tau = \frac{3fl}{2bt^2}$$

Where τ is the flexural strength, f is the load, l is the gauge length, b is the width and t is the thickness of the specimen under test.

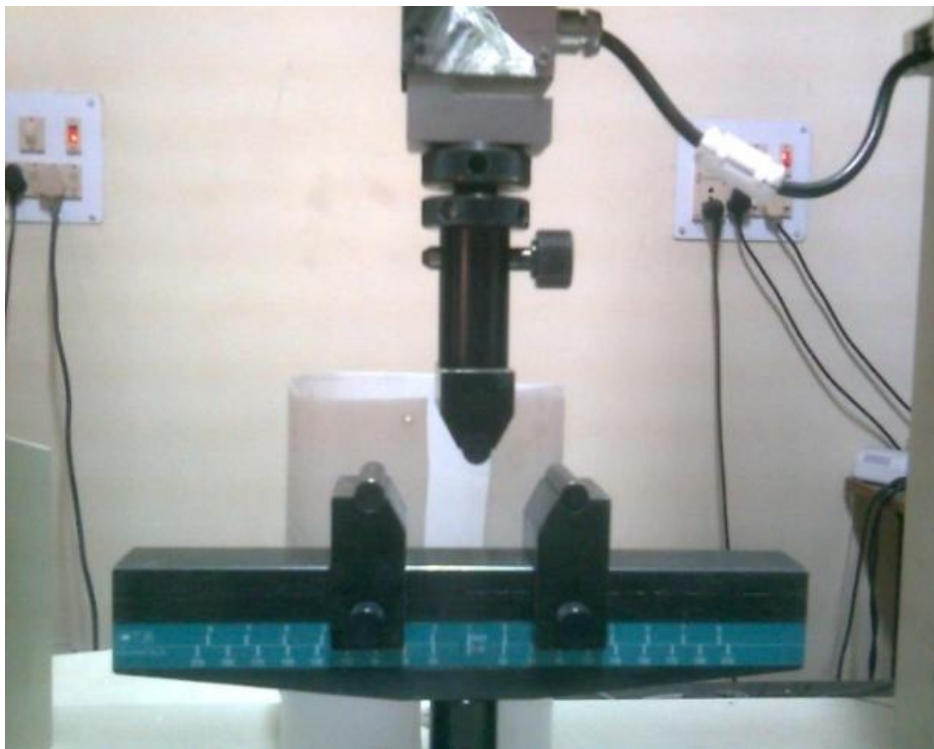


Figure 3.5 UTM machine sample unloaded for flexural testing

3.4.3 Results and discussion

3.4.3.1 Moisture absorption behaviour

The results of both untreated and treated fibre composite samples exposed to different environments are shown in Table-3.1 to 3.24.

Figure-3.22 to 3.29 shows the percentage of moisture absorption characteristics of composite samples with untreated and treated fiber exposed to Saline water and Distil environment with time. It is quite obvious from the figure that as the fibre content increases, the initial rate of moisture absorption and the maximum moisture absorption for both the environment increases. Moisture absorption is maximum for three layered composites. It is known that, the factors like adhesion between fibre and matrix, porosity content and the lumen are responsible for the moisture absorption behaviour of the natural fibre composites. But in this case the hydrophilicity of *Luffa Cylindrica* fiber, in addition to poor adhesion between fiber–matrix and voids content might have affect the moisture uptake characteristics of the composite.

Again it is observed that, the moisture absorption increases as the immersion time increases, and got saturated after certain time period. Time required to reach the saturation point is not same for both the environments. The saturation time is approximately 120 hrs for distil, and 108 hrs for saline water. Environmental conditions also play a significant role in moisture absorption process. Figure-3.30 to 3.33 shows the maximum moisture absorption of composite in all three environments. In Distil Water environment moisture absorption is maximum as compare to saline water environment. The rate of absorption in case of saline water is low as compared to steam. This happens because of the gathering of NaCl ions in the fibre's surface immersed in saline water, which increases with time and delays moisture diffusion [122].

Figure-3.22 to 3.29 shows that the moisture absorption behaviour of the chemically treated fibre reinforced epoxy composites was lesser than that of the untreated fibre when exposed to different environmental treatment. It is clear from these plots that the change in surface chemistry of the fibre reduces the attraction of fibers to moisture. Due to surface modification by chemical treatment, the fibers get covered with the epoxy resin with a stronger adhesion, resulting in less moisture uptake.

3.4.3.2 Measurement of Diffusivity

The water sorption kinetics in LCF reinforced epoxy composite has been studied through the diffusion constants k and n . The behaviour of moisture sorption in the composite was studied by the shape of the curve represented by the equation (3.3) [37, 38]:

$$\frac{M_t}{M_m} = kt^n \quad (3.3)$$

Where, M_t is the moisture content at specific time 't',

M_m is the equilibrium moisture content (EMC), and

k and n are constants.

The value of k and n were found out from the slope and the intercept of M_t / M_m versus time 't' in the log plot which was drawn from the data obtained from experiment of moisture absorption with time. Figure-3.14 to 3.16 and Figure-3.17 to 3.19 showed the typical curve of $\log (M_t/M_m)$ as a function of $\log (t)$ for both untreated and treated LCF reinforced epoxy composite respectively, used to determine these constants. The values of k and n resulting from the fitting of all formulations are shown in Table-3.25 and 3.26. It was observed that the value of n is close to 0.9 for all of the composites. This confirms that the Fickian diffusion can be used to adequately describe moisture absorption in the composites. A higher value of n and k indicates that the composite needs shorter time to attain equilibrium water absorption. The value of k was found to increase with increasing fibre content for LCF reinforced epoxy composite in all environments resulting in higher moisture absorption initially. The value of k for untreated fiber composite was higher than that of treated fiber composite, except in a saline water environment. It might have happened due to the gathering of NaCl ions in the fiber's surface which delays subsequent moisture diffusion.

The diffusion coefficient or diffusivity (D_x) of moisture absorption was calculated using the following equation:

$$D_x = \pi \left[\frac{h}{4M_m} \right]^2 \left(\frac{M_2 - M_1}{\sqrt{t_2} - \sqrt{t_1}} \right)^2 \quad (3.4)$$

where ' M_m ' is the maximum percentage of moisture content, ' h ' is the sample thickness, ' t_1 ' and ' t_2 ' are the selected points in the initial linear portion of the plot of moisture absorption (M_t) versus \sqrt{t} (Figure-3.21) and ' M_1 ' and ' M_2 ' are the respective moisture content.

From the plot of M_t verses square root of time (t) the value of D_x has been evaluated and summarized in Table-3.27 and 3.28. It has been observed D_x value increases with the LCF content for the composites examined. These results are consistent with previous findings on wood and natural fibers composites. The increase was more pronounced for the specimens subjected to steam than those subjected to saline water and sub-zero environments. The surface modification of fiber decreases the diffusion coefficient (D_x).

3.4.4 Effect of moisture absorption on Mechanical properties

The mechanical properties of the natural fibre polymer composite were greatly influenced by the moisture absorption. Figure-3.6 to 3.13 shows the result of mechanical properties of the composite with both treated and untreated fibre reinforced composite after expose to different environment for a period of 156 hrs. It has been observed that, both strength and stiffness of all composite decrease after moisture absorption. This reduction in the stiffness and strength is accredited to the changes occurring in the fibre, and the interface between fibre and matrix. When fibre/matrix interface is exposed to moisture from the environment, the cellulosic fibers tend to swell, thereby developing shear stresses at the interface, which favours ultimate debonding of the fibers, which in turn causes strength reduction [85]. It is also observed that the reduction in properties was greatly influenced by the fibre loading and nature of environment. The maximum reduction in strength and stiffness occurred in case of three layered composite in both the environments. Further it is also noticed that the amount of decrease in mechanical properties is reduced with chemical modification of fibre. The alkali treated fibre composite exhibits the best result in both the environments in

comparison to other untreated fibre composite. Because the alkali treatment reduces the hydrophilic nature of the fibre to great extent which leads to less moisture absorption.

3.4 CONCLUSIONS

Based on experimental results, this study has led to the following conclusions:

- The Luffa Cylindricafibre can successfully be used as reinforcing agent to fabricate composite by suitably bonding with epoxy resin. .
- On increasing the fibre content the strength, modulus and work of fracture increases and the best combination is found with Double Layered composite.
- The fibre surface modification by chemical treatments significantly improves the fibre matrix adhesion, which in turn improves the mechanical properties of composite.
- The moisture uptake and thickness swelling values increases with increase in fiber loading. Both values are found to be higher in saline environment than in distil water environments. However these values are considerably reduced with chemical treatments of the fibre.
- Under all environment conditions, the moisture diffusion process of both treated and untreated Luffa Cylindricafibre composites are found to follow the Fick's law.
- Fibre breakages are found to be the predominant mode of failure as ascertained from the morphology of the treated fibre composites.

Table–3.1. Variation of weight gain and thickness swelling of untreated Luffa Cylindrica fibre epoxy composite (flexural) with immersion time expose at distil environment.

No. of layers	Immersion Time ‘t’ (hrs)	Weight of the Sample	Percentage of weight gain (%M)	Thickness at time ‘t’ H(t)	Thickness Swelling TS (t)
Single Layer	0	12.761	0	0.59	0
	12	12.986	1.763184703	0.591	0.169491525
	24	13.038	2.170676279	0.592	0.338983051
	36	13.063	2.366585691	0.593	0.508474576
	48	13.136	2.938641172	0.594	0.677966102
	60	13.213	3.54204216	0.595	0.847457627
	72	13.228	3.659587807	0.596	1.016949153
	84	13.253	3.855497218	0.597	1.186440678
	96	13.283	4.090588512	0.598	1.355932203
	108	13.486	5.681372933	0.599	1.525423729
	120	13.598	6.559047097	0.6	1.694915254
	132	13.598	6.559047097	0.6	1.694915254
	144	13.598	6.559047097	0.6	1.694915254
	156	13.599	6.566883473	0.6	1.694915254

Table–3.2 Variation of weight gain and thickness swelling of treated *Luffa Cylindrica* fibre epoxy composite (flexural) with immersion time expose at distil environment.

No. of layers	Immersion Time ‘t’ (hrs)	Weight of the Sample	Percentage of weight gain (%M)	Thickness at time ‘t’ H(t)	Thickness Swelling TS (t)
Double Layer	0	15.504	0	0.707	0
Sample 3	12	15.954	2.90247678	0.709	0.282885431
	24	16.123	3.99251806	0.71	0.424328147
	36	16.421	5.914602683	0.713	0.848656294
	48	16.652	7.404540764	0.715	1.131541726
	60	16.669	7.514189886	0.717	1.414427157
	72	16.701	7.720588235	0.719	1.697312588
	84	16.821	8.494582043	0.721	1.98019802
	96	17.015	9.745872033	0.723	2.263083451
	108	17.125	10.45536636	0.725	2.545968883
	120	17.131	10.49406605	0.726	2.687411598
	132	17.131	10.49406605	0.726	2.687411598
	144	17.132	10.500516	0.726	2.687411598
	156	17.132	10.500516	0.726	2.687411598

Table–3.3 Variation of weight gain and thickness swelling of treated Luffa Cylindrica fibre epoxy composite (flexural) with immersion time expose at distil environment.

No. of layers	Immersion Time ‘t’ (hrs)	Weight of the Samples	Percentage of weight gain (%M)	Thickness at time ‘t’ H(t)	Thickness Swelling TS (t)
Triple Layer	0	16.974	0	1.125	0
Sample 5	12	18.166	7.02250501	1.128	0.266666667
	24	18.414	8.4835631	1.132	0.622222222
	36	18.831	10.9402616	1.136	0.977777778
	48	19.162	12.8903028	1.14	1.333333333
	60	19.284	13.6090491	1.143	1.6
	72	19.373	14.1333805	1.147	1.955555556
	84	19.622	15.6003299	1.15	2.222222222
	96	19.726	16.2130317	1.154	2.577777778
	108	19.767	16.4545776	1.158	2.933333333
	120	19.921	17.3618475	1.162	3.288888889
	132	20.11	18.4753152	1.162	3.288888889
	144	20.112	18.4870979	1.162	3.288888889
	156	20.112	18.4870979	1.162	3.288888889

Table–3.4 Variation of weight gain and thickness swelling of treated *Luffa Cylindrica* fibre epoxy composite (tensile) with immersion time expose at distil environment.

No. of layers	Immersion Time ‘t’ (hrs)	Weight of the sample	Percentage of weight gain (%M)	Thickness At time ‘t’ H(t)	Thickness Swelling TS (t)
Single Layer	0	11.801	0	0.637	0
	12	12.124	2.737056182	0.638	0.156985871
	24	12.234	3.669180578	0.639	0.313971743
	36	12.342	4.584357258	0.64	0.470957614
	48	12.410	5.160579612	0.641	0.627943485
	60	12.564	6.465553767	0.642	0.784929356
	72	12.671	7.372256588	0.643	0.941915228
	84	12.784	8.329802559	0.644	1.098901099
	96	12.897	9.28734853	0.645	1.25588697
	108	12.994	10.10931277	0.646	1.412872841
	120	12.994	10.10931277	0.647	1.569858713
	132	12.994	10.10931277	0.647	1.569858713
	144	12.994	10.10931277	0.647	1.569858713
	156	12.994	10.10931277	0.647	1.569858713

Table–3.5 Variation of weight gain and thickness swelling of treated Luffa Cylindrica fibre epoxy composite (tensile) with immersion time expose at distil environment.

No. of layers	Immersion Time 't' (hrs)	Weight of the Sample	Percentage of weight gain (%M)	Thickness at time 't' H(t)	Thickness Swelling TS (t)
Double Layer	0	13.602	0	0.713	0
	12	13.847	1.80120571	0.715	0.280504909
	24	14.145	3.99205999	0.717	0.561009818
	36	14.354	5.52859874	0.719	0.841514727
	48	14.557	7.02102632	0.721	1.122019635
	60	14.743	8.38847228	0.723	1.402524544
	72	14.957	9.96177033	0.725	1.683029453
	84	15.147	11.3586237	0.727	1.963534362
	96	15.354	12.8804588	0.729	2.244039271
	108	15.145	13.6965152	0.731	2.52454418
	120	15.465	13.6965152	0.733	2.805049088
	132	15.465	13.6965152	0.733	2.805049088
	144	15.465	13.6965152	0.733	2.805049088
	156	15.465	13.6965152	0.733	2.805049088

Table–3.6 Variation of weight gain and thickness swelling of treated Luffa Cylindrica fibre epoxy composite (tensile) with immersion time expose at distil environment.

No. of layers	Immersion Time ‘t’ (hrs)	Weight of the Sample	Percentage of weight gain (%M)	Thickness at time ‘t’ H(t)	Thickness Swelling TS (t)
Triple Layer	0	14.688	0	1.125	0
Sample 3	12	15.128	2.9956427	1.129	0.355555556
	24	15.547	5.84831155	1.134	0.8
	36	15.947	8.57162309	1.137	1.066666667
	48	16.374	11.4787582	1.141	1.422222222
	60	16.654	13.3850763	1.144	1.688888889
	72	16.957	15.4479847	1.147	1.955555556
	84	17.324	17.9466231	1.15	2.222222222
	96	17.674	20.3295207	1.154	2.577777778
	108	18.957	22.2562636	1.158	2.933333333
	120	18.957	22.2562636	1.162	3.288888889
	132	18.957	22.2562636	1.162	3.288888889
	144	18.957	22.2562636	1.162	3.288888889
	156	18.957	22.2562636	1.162	3.288888889

Table–3.7 Variation of weight gain and thickness swelling of treated *Luffa Cylindrica* fibre epoxy composite (flexural) with immersion time expose at distil environment.

No. of layers	Time of immersion	Final Wt.	Wt. Change	Thickness	Thickness Swelling
Single layer	0	14.138	0	0.617	0
	12	14.235	0.686094214	0.618	0.162074554
	24	14.358	1.55608997	0.619	0.324149109
	36	14.487	2.468524544	0.62	0.486223663
	48	14.541	2.8504739	0.621	0.648298217
	60	14.635	3.515348706	0.622	0.810372771
	72	14.741	4.265101146	0.623	0.972447326
	84	14.852	5.050219267	0.624	1.13452188
	96	14.957	5.792898571	0.625	1.296596434
	108	14.972	5.898995615	0.626	1.458670989
	120	14.972	5.898995615	0.626	1.458670989
	132	14.972	5.898995615	0.626	1.458670989
	144	14.972	5.898995615	0.626	1.458670989
	156	14.972	5.898995615	0.626	1.458670989

Table–3.8 Variation of weight gain and thickness swelling of untreated Luffa Cylindrica fibre epoxy composite (flexural) with immersion time expose at distil environment.

No. of layers	Time of immersion	Final Wt.	Wt. Change	Thickness	Thickness Swelling
Double layer	0	12.367	0	0.499	0
	12	12.523	1.261421525	0.501	0.400801603
	24	12.745	3.056521388	0.503	0.801603206
	36	12.941	4.641384329	0.505	1.20240481
	48	13.102	5.943236031	0.507	1.603206413
	60	13.304	7.576615186	0.509	2.004008016
	72	13.516	9.290854694	0.511	2.404809619
	84	13.712	10.87571764	0.513	2.805611222
	96	13.923	12.58187111	0.515	3.206412826
	108	14.001	13.21258187	0.517	3.607214429
	120	14.001	13.21258187	0.517	3.607214429
	132	14.001	13.21258187	0.517	3.607214429
	144	14.001	13.21258187	0.517	3.607214429
	156	14.001	13.21258187	0.517	3.607214429

Table–3.9 Variation of weight gain and thickness swelling of untreated Luffa Cylindrica fibre epoxy composite (flexural) with immersion time expose at distil environment.

No. of layers	Time of immersion	Final Wt.	Wt. Change	Thickness	Thickness Swelling
Triple layer	0	19.295	0	0.866	0
	12	19.547	1.306037834	0.87	0.461893764
	24	19.925	3.265094584	0.874	0.923787529
	36	20.218	4.7836227	0.879	1.501154734
	48	20.754	7.561544442	0.884	2.07852194
	60	20.998	8.826120757	0.888	2.540415704
	72	21.456	11.19979269	0.892	3.002309469
	84	21.879	13.39207048	0.896	3.464203233
	96	22.241	15.2682042	0.902	4.15704388
	108	22.741	17.85954911	0.906	4.618937644
	120	22.741	17.85954911	0.906	4.618937644
	132	22.741	17.85954911	0.906	4.618937644
	144	22.741	17.85954911	0.906	4.618937644
	156	22.741	17.85954911	0.906	4.618937644

Table–3.10 Variation of weight gain and thickness swelling of untreated Luffa Cylindrica fibre epoxy composite (tensile) with immersion time expose at distil environment.

No. of layers	Time of immersion	Final Wt.	Wt. Change	Thickness	Thickness Swelling
SL	0	11.199	0	0.54	0
	12	11.247	0.428609697	0.541	0.185185185
	24	11.395	1.750156264	0.542	0.37037037
	36	11.551	3.14313778	0.543	0.555555556
	48	11.628	3.83069917	0.544	0.740740741
	60	11.784	5.223680686	0.545	0.925925926
	72	11.871	6.000535762	0.546	1.111111111
	84	11.967	6.857755157	0.547	1.296296296
	96	12.117	8.197160461	0.548	1.481481481
	108	12.228	9.188320386	0.549	1.666666667
	120	12.374	10.49200822	0.549	1.666666667
	132	12.374	10.49200822	0.549	1.666666667
	144	12.374	10.49200822	0.549	1.666666667
	156	12.374	10.49200822	0.549	1.666666667

Table–3.11 Variation of weight gain and thickness swelling of untreated Luffa Cylindrica fibre epoxy composite (tensile) with immersion time expose at distil environment.

No. of layers	Time of immersion	Final Wt.	Wt. Change	Thickness	Thickness Swelling
DL	0	11.995	0	0.591	0
Sample 2	12	12.108	0.942059191	0.593	0.338409475
	24	12.354	2.992913714	0.595	0.676818951
	36	12.546	4.593580659	0.597	1.015228426
	48	12.821	6.886202584	0.599	1.353637902
	60	12.983	8.236765319	0.601	1.692047377
	72	13.099	9.203834931	0.603	2.030456853
	84	13.212	10.14589412	0.605	2.368866328
	96	13.521	12.72196749	0.607	2.707275804
	108	13.715	14.33930805	0.609	3.045685279
	120	13.715	14.33930805	0.609	3.045685279
	132	13.715	14.33930805	0.609	3.045685279
	144	13.715	14.33930805	0.609	3.045685279
	156	13.715	14.33930805	0.609	3.045685279

Table–3.12 Variation of weight gain and thickness swelling of untreated Luffa Cylindrica fibre epoxy composite (tensile) with immersion time expose at distil environment.

No. of layers	Time of immersion	Final Wt.	Wt. Change	Thickness	Thickness Swelling
TL	0	13.046	0	0.668	0
Sample 1	12	13.398	2.698145025	0.671	0.449101796
	24	13.604	4.27717308	0.674	0.898203593
	36	13.951	6.936992182	0.677	1.347305389
	48	14.314	9.719454239	0.68	1.796407186
	60	14.618	12.0496704	0.683	2.245508982
	72	14.983	14.84746282	0.686	2.694610778
	84	15.287	17.17767898	0.689	3.143712575
	96	15.549	19.18595738	0.692	3.592814371
	108	15.895	21.8381113	0.695	4.041916168
	120	15.895	22.61996014	0.695	4.041916168
	132	15.895	22.61996014	0.695	4.041916168
	144	15.895	22.61996014	0.695	4.041916168
	156	15.895	22.61996014	0.695	4.041916168

Table–3.13 Variation of weight gain and thickness swelling of untreated Luffa Cylindrica fibre epoxy composite (flexural) with immersion time expose at saline environment.

No. of layers	Time of immersion	Final Wt.	Wt. Change	Thickness	Thickness Swelling
Single Layer	0	11.836	0	0.55	0
	12	12.014	1.503886448	0.551	0.181818182
	24	12.18	2.906387293	0.552	0.363636364
	36	12.291	3.844204123	0.553	0.545454545
	48	12.368	4.494761744	0.554	0.727272727
	60	12.532	5.880364988	0.555	0.909090909
	72	12.741	7.646164245	0.556	1.090909091
	84	12.887	8.879689084	0.557	1.272727273
	96	12.913	9.099357891	0.558	1.454545455
	108	12.998	9.817505914	0.559	1.636363636
	120	12.998	9.817505914	0.559	1.636363636
	132	12.998	9.817505914	0.559	1.636363636
	144	12.998	9.817505914	0.559	1.636363636
	156	12.998	9.817505914	0.559	1.636363636

Table–3.14 Variation of weight gain and thickness swelling of treated *Luffa Cylindrica* fibre epoxy composite (tensile) with immersion time expose at saline environment.

No. of layers	Time of immersion	Final Wt.	Wt. Change	Thickness	Thickness Swelling
Double Layer	0	15.665	0	0.769	0
	12	15.821	0.995850622	0.771	0.260078023
	24	16.246	3.708905203	0.773	0.520156047
	36	16.521	5.464411108	0.775	0.78023407
	48	16.825	7.40504309	0.777	1.040312094
	60	16.993	8.477497606	0.779	1.300390117
	72	17.241	10.06064475	0.781	1.56046814
	84	17.521	11.84806894	0.783	1.820546164
	96	17.724	13.14395148	0.785	2.080624187
	108	17.928	14.44621768	0.787	2.340702211
	120	17.928	14.44621768	0.787	2.340702211
	132	17.928	14.44621768	0.787	2.340702211
	144	17.928	14.44621768	0.787	2.340702211
	156	17.928	14.44621768	0.787	2.340702211

Table–3.15 Variation of weight gain and thickness swelling of treated *Luffa Cylindrica* fibre epoxy composite (flexural) with immersion time expose at saline environment.

No. of layers	Time of immersion	Final Wt.	Wt. Change	Thickness	Thickness Swelling
Triple layer	0	17.75	0	1.113	0
	12	18.324	3.233802817	1.117	0.359389039
	24	18.925	6.61971831	1.121	0.718778077
	36	19.363	9.087323944	1.124	0.988319856
	48	19.724	11.12112676	1.128	1.347708895
	60	19.947	12.37746479	1.131	1.617250674
	72	20.259	14.13521127	1.135	1.976639712
	84	20.624	16.1915493	1.14	2.425876011
	96	20.989	18.24788732	1.145	2.875112309
	108	21.112	18.94084507	1.148	3.144654088
	120	21.112	18.94084507	1.148	3.144654088
	132	21.112	18.94084507	1.148	3.144654088
	144	21.112	18.94084507	1.148	3.144654088
	156	21.112	18.94084507	1.148	3.144654088

Table–3.16 Variation of weight gain and thickness swelling of untreated Luffa Cyndrica fibre epoxy composite (tensile) with immersion time expose at saline environment.

No. of layers	Time of immersion	Initial Wt.	Final Wt.	Wt. Change	Thickness	Thickness Swelling
Single layer	0	10.658	10.658	0	0.553	0
	12	10.658	10.692	0.319009195	0.554	0.180831826
	24	10.658	10.702	0.412835429	0.555	0.361663653
	36	10.658	10.742	0.788140364	0.556	0.542495479
	48	10.658	10.799	1.322949897	0.557	0.723327306
	60	10.658	11.121	4.344154626	0.558	0.904159132
	72	10.658	11.354	6.530305874	0.559	1.084990958
	84	10.658	11.582	8.669544005	0.56	1.265822785
	96	10.658	11.81	10.80878214	0.561	1.446654611
	108	10.658	12.128	13.79245637	0.562	1.627486438
	120	10.658	12.421	16.54156502	0.563	1.808318264
	132	10.658	12.421	16.54156502	0.563	1.808318264
	144	10.658	12.421	16.54156502	0.563	1.808318264
	156	10.658	12.421	16.54156502	0.563	1.808318264

Table–3.17 Variation of weight gain and thickness swelling of treated *Luffa Cylindrica* fibre epoxy composite (tensile) with immersion time expose at saline environment.

No. of layers	Time of immersion	Final Wt.	Wt. Change	Thickness	Thickness Swelling
Double layer	0	14.752	0	0.736	0
	12	14.854	0.69143167	0.738	0.27173913
	24	14.986	1.586225597	0.74	0.543478261
	36	15.285	3.613069414	0.742	0.815217391
	48	15.587	5.660249458	0.744	1.086956522
	60	15.921	7.924349241	0.746	1.358695652
	72	16.231	10.02575922	0.748	1.630434783
	84	16.752	13.55748373	0.75	1.902173913
	96	17.254	16.96041215	0.752	2.173913043
	108	17.753	20.34300434	0.754	2.445652174
	120	18.285	23.94929501	0.756	2.717391304
	132	18.285	23.94929501	0.756	2.717391304
	144	18.285	23.94929501	0.756	2.717391304
	156	18.285	23.94929501	0.756	2.717391304

Table–3.18 Variation of weight gain and thickness swelling of untreated Luffa Cylindrica fibre epoxy composite (tensile) with immersion time expose at saline environment.

No. of layers	Time of immersion	Final Wt.	Wt. Change	Thickness	Thickness Swelling
Triple layer	0	15.513	0	1.095	0
	12	15.999	3.132856314	1.099	0.365296804
	24	16.487	6.278605041	1.102	0.639269406
	36	16.956	9.301875846	1.106	1.00456621
	48	17.541	13.07290659	1.11	1.369863014
	60	17.982	15.91568362	1.114	1.735159817
	72	18.421	18.74556823	1.118	2.100456621
	84	18.924	21.98801006	1.122	2.465753425
	96	19.421	25.19177464	1.126	2.831050228
	108	19.862	28.03455167	1.13	3.196347032
	120	20.102	29.5816412	1.134	3.561643836
	132	20.102	29.5816412	1.134	3.561643836
	144	20.102	29.5816412	1.134	3.561643836
	156	20.102	29.5816412	1.134	3.561643836

Table–3.19 Variation of weight gain and thickness swelling of treated *Luffa Cylindrica* fibre epoxy composite (flexural) with immersion time expose at saline environment.

No. of layers	Time of immersion	Final Wt.	Wt. Change	Thickness	Thickness Swelling
Single layer	0	14.044	0	0.582	0
	12	14.103	0.420108231	0.583	0.171821306
	24	14.204	1.139276559	0.584	0.343642612
	36	14.312	1.908288237	0.585	0.515463918
	48	14.432	2.762745657	0.586	0.687285223
	60	14.514	3.346624893	0.587	0.859106529
	72	14.617	4.080034178	0.588	1.030927835
	84	14.734	4.913130162	0.589	1.202749141
	96	14.854	5.767587582	0.59	1.374570447
	108	14.921	6.244659641	0.591	1.546391753
	120	14.921	6.244659641	0.591	1.546391753
	132	14.921	6.244659641	0.591	1.546391753
	144	14.921	6.244659641	0.591	1.546391753
	156	14.921	6.244659641	0.591	1.546391753

Table–3.20 Variation of weight gain and thickness swelling of untreated Luffa Cylindrica fibre epoxy composite (flexural) with immersion time expose at saline environment.

No. of layers	Time of immersion	Final Wt.	Wt. Change	Thickness	Thickness Swelling
Double layer	0	12.614	0	0.582	0
	12	12.732	0.935468527	0.584	0.343642612
	24	12.874	2.061201839	0.586	0.687285223
	36	12.948	2.647851593	0.588	1.030927835
	48	13.098	3.837006501	0.59	1.374570447
	60	13.199	4.637704138	0.592	1.718213058
	72	13.314	5.549389567	0.594	2.06185567
	84	13.487	6.92088156	0.596	2.405498282
	96	13.589	7.729506897	0.598	2.749140893
	108	13.754	9.037577295	0.6	3.092783505
	120	13.754	9.037577295	0.6	3.092783505
	132	13.754	9.037577295	0.6	3.092783505
	144	13.754	9.037577295	0.6	3.092783505
	156	13.754	9.037577295	0.6	3.092783505

Table–3.21 Variation of weight gain and thickness swelling of untreated Luffa Cylindrica fibre epoxy composite (flexural) with immersion time expose at saline environment.

No. of layers	Time of immersion	Final Wt.	Wt. Change	Thickness	Thickness Swelling
Triple layer	0	19.182	0	0.846	0
	12	19.321	0.724637681	0.85	0.472813239
	24	19.628	2.325096445	0.854	0.945626478
	36	19.825	3.352100928	0.858	1.418439716
	48	20.087	4.717964759	0.862	1.891252955
	60	20.257	5.604212282	0.866	2.364066194
	72	20.524	6.996142217	0.87	2.836879433
	84	20.784	8.351579606	0.873	3.191489362
	96	20.987	9.409863414	0.876	3.546099291
	108	21.238	10.71838182	0.879	3.90070922
	120	21.238	10.71838182	0.879	3.90070922
	132	21.238	10.71838182	0.879	3.90070922
	144	21.238	10.71838182	0.879	3.90070922
	156	21.238	10.71838182	0.879	3.90070922

Table–3.22 Variation of weight gain and thickness swelling of treated *Luffa Cylindrica* fibre epoxy composite (tensile) with immersion time expose at saline environment.

No. of layers	Time of immersion	Final Wt.	Wt. Change	Thickness	Thickness Swelling
Single layer	0	11.902	0	0.514	0
	12	11.961	0.495715006	0.515	0.194552529
	24	12.015	0.949420266	0.516	0.389105058
	36	12.069	1.403125525	0.517	0.583657588
	48	12.121	1.840026886	0.518	0.778210117
	60	12.168	2.234918501	0.519	0.972762646
	72	12.224	2.705427659	0.52	1.167315175
	84	12.274	3.125525122	0.521	1.361867704
	96	12.324	3.545622584	0.522	1.556420233
	108	12.398	4.167366829	0.523	1.750972763
	120	12.398	4.167366829	0.523	1.750972763
	132	12.398	4.167366829	0.523	1.750972763
	144	12.398	4.167366829	0.523	1.750972763
	156	12.398	4.167366829	0.523	1.750972763

Table–3.23 Variation of weight gain and thickness swelling of untreated Luffa Cylindrica fibre epoxy composite (tensile) with immersion time expose at saline environment.

No. of layers	Time of immersion	Final Wt.	Wt. Change	Thickness	Thickness Swelling
Double layer	0	11.599	0	0.601	0
	12	11.717	1.01732908	0.603	0.332778702
	24	11.835	2.03465816	0.605	0.665557404
	36	11.953	3.05198724	0.607	0.998336106
	48	12.071	4.06931632	0.609	1.331114809
	60	12.189	5.0866454	0.611	1.663893511
	72	12.307	6.103974481	0.613	1.996672213
	84	12.425	7.121303561	0.615	2.329450915
	96	12.543	8.138632641	0.617	2.662229617
	108	12.661	9.155961721	0.619	2.995008319
	120	12.661	9.155961721	0.619	2.995008319
	132	12.661	9.155961721	0.619	2.995008319
	144	12.661	9.155961721	0.619	2.995008319
	156	12.661	9.155961721	0.619	2.995008319

Table–3.24 Variation of weight gain and thickness swelling of treated *Luffa Cylindrica* fibre epoxy composite (tensile) with immersion time expose at saline environment.

No. of layers	Time of immersion	Final Wt.	Wt. Change	Thickness	Thickness Swelling
Triple layer	0	17.351	0	0.852	0
	12	17.621	1.556106276	0.856	0.469483568
	24	17.925	3.308166676	0.859	0.821596244
	36	18.147	4.587631837	0.863	1.291079812
	48	18.462	6.403089159	0.867	1.76056338
	60	18.741	8.011065645	0.87	2.112676056
	72	18.981	9.394271224	0.873	2.464788732
	84	19.241	10.89274393	0.876	2.816901408
	96	19.524	12.52377385	0.878	3.051643192
	108	19.851	14.40839145	0.88	3.286384977
	120	19.851	14.40839145	0.88	3.286384977
	132	19.851	14.40839145	0.88	3.286384977
	144	19.851	14.40839145	0.88	3.286384977
	156	19.851	14.40839145	0.88	3.286384977

Table-3.25 Diffusion case selection parameters (Flexural Samples)

Environment	No. of layers	Type of Fiber	n	k(h²)
Distil Water	SL	Untreated	0.5523	0.0682
	DL	Untreated	1.0653	0.0184
	TL	Untreated	1.0855	0.0501
	SL	Alkali Treated	1.0886	0.0344
	DL	Alkali Treated	0.8983	0.1175
	TL	Alkali Treated	0.6416	0.4265
Saline Water	SL	Untreated	1.0903	0.0293
	DL	Untreated	1.037	0.022
	TL	Untreated	1.0497	0.0506
	SL	Alkali Treated	1.0626	0.0164
	DL	Alkali Treated	1.0687	0.035
	TL	Alkali Treated	1.0007	0.1838

Table-3.26 Diffusion case selection parameters (Tensile Samples)

Environment	No. of layers	Type of Fiber	n	k(h²)
Distil Water	SL	Untreated	1.0975	0.0979
	DL	Untreated	1.066	0.0179
	TL	Untreated	0.9814	0.1338
	SL	Alkali Treated	0.9126	0.0837
	DL	Alkali Treated	1.0863	0.0549
	TL	Alkali Treated	1.0832	0.0363
Saline Water	SL	Untreated	1.0626	0.0119
	DL	Untreated	1.0315	0.0167
	TL	Untreated	1.0311	0.0939
	SL	Alkali Treated	1.0508	0.0227
	DL	Alkali Treated	1.0052	0.0238
	TL	Alkali Treated	1.0168	0.058

**Table-3.27 Diffusivity of untreated and treated fiber Luffa Cylindrica
fiber epoxy composites at different environments**

Environment	No. of layers	Type of Fiber	Diffusivity (D_x) $\times 10^{-4}$
Distil Water	SL	Untreated	1.3235
	DL	Untreated	4.7109
	TL	Untreated	10.560
	SL	Alkali Treated	5.4702
	DL	Alkali Treated	3.0626
	TL	Alkali Treated	8.1415
Saline Water	SL	Untreated	1.2311
	DL	Untreated	3.3674
	TL	Untreated	8.7999
	SL	Alkali Treated	4.4222
	DL	Alkali Treated	2.0858
	TL	Alkali Treated	4.0218

**Table-3.28 Diffusivity of untreated and treated fiber Luffa Cylindrica
fiber epoxy composites at different environments**

Environment	No. of layers	Type of Fiber	Diffusivity (D_x) $\times 10^{-4}$
Distil Water	SL	Untreated	2.2475
	DL	Untreated	4.5690
	TL	Untreated	8.6533
	SL	Alkali Treated	3.5448
	DL	Alkali Treated	3.7451
	TL	Alkali Treated	6.2147
Saline Water	SL	Untreated	1.2457
	DL	Untreated	3.8521
	TL	Untreated	7.7462
	SL	Alkali Treated	3.5847
	DL	Alkali Treated	2.1458
	TL	Alkali Treated	6.0128

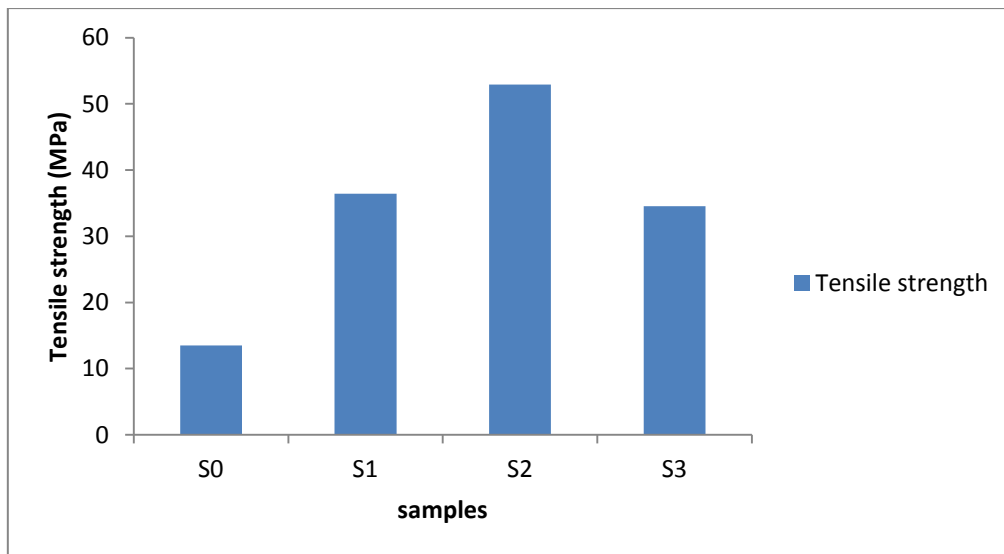


Figure-3.6 Variation of tensile strength with different layers of untreated *Luffa Cylindrica* fibre epoxy composites exposed to saline water environment.

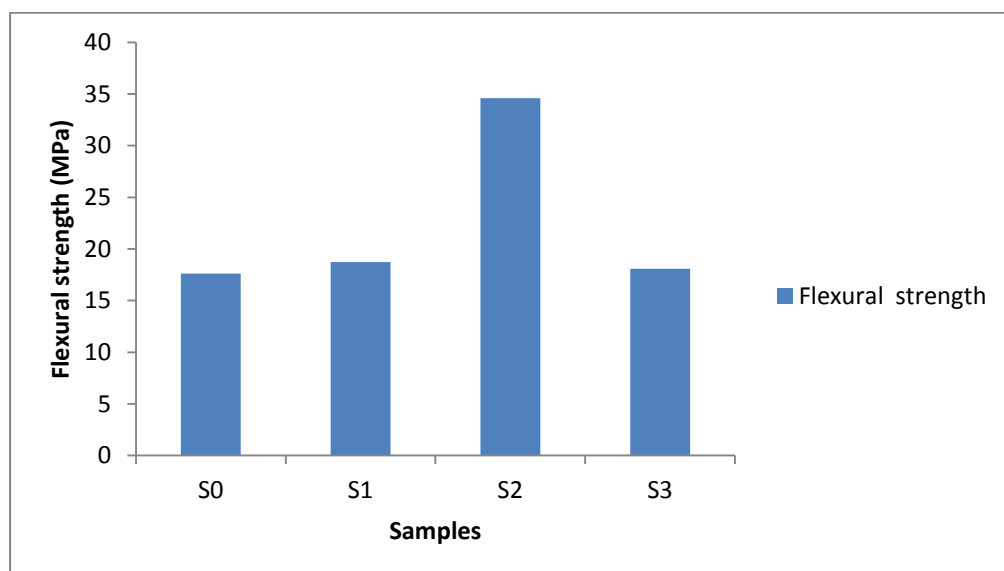


Figure-3.7 Variation of flexural strength with different layers of untreated *Luffa Cylindrica* fibre epoxy composites exposed to saline water environment.

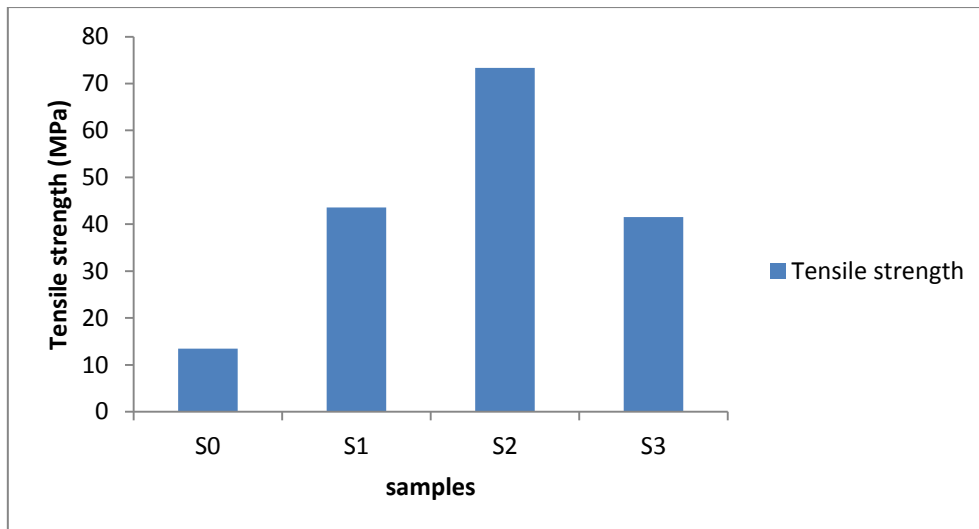


Figure-3.8 Variation of tensile strength with different layers of untreated *Luffa Cylindrica* fibre epoxy composites exposed to distil water environment.

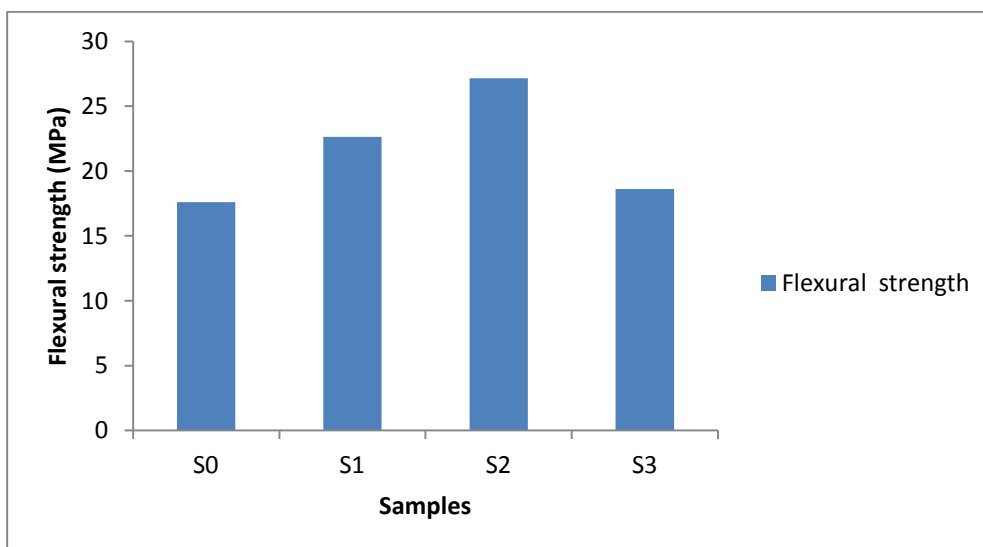


Figure-3.9 Variation of flexural strength with different layers of untreated *Luffa Cylindrica* fibre epoxy composites exposed to distil water environment.

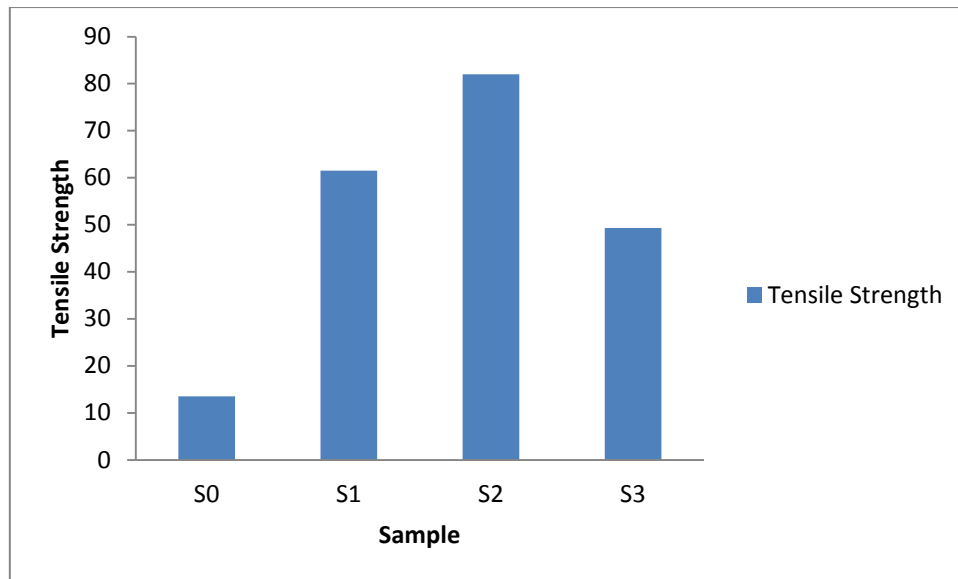


Figure-3.10 Variation of tensile strength with different layers of treated *Luffa Cylindrica* fibre epoxy composites exposed to saline water environment.

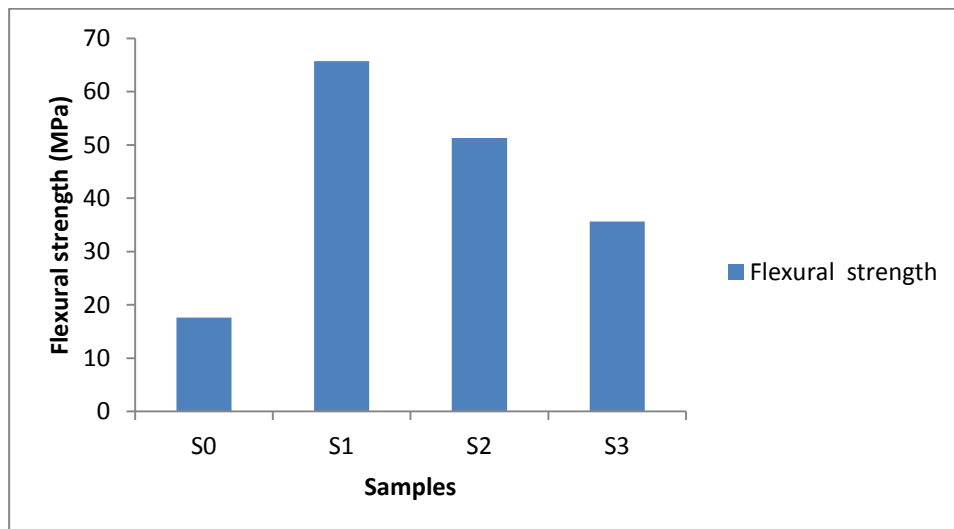


Figure-3.11 Variation of flexural strength with different layers of treated *Luffa Cylindrica* fibre epoxy composites exposed to saline water environment.

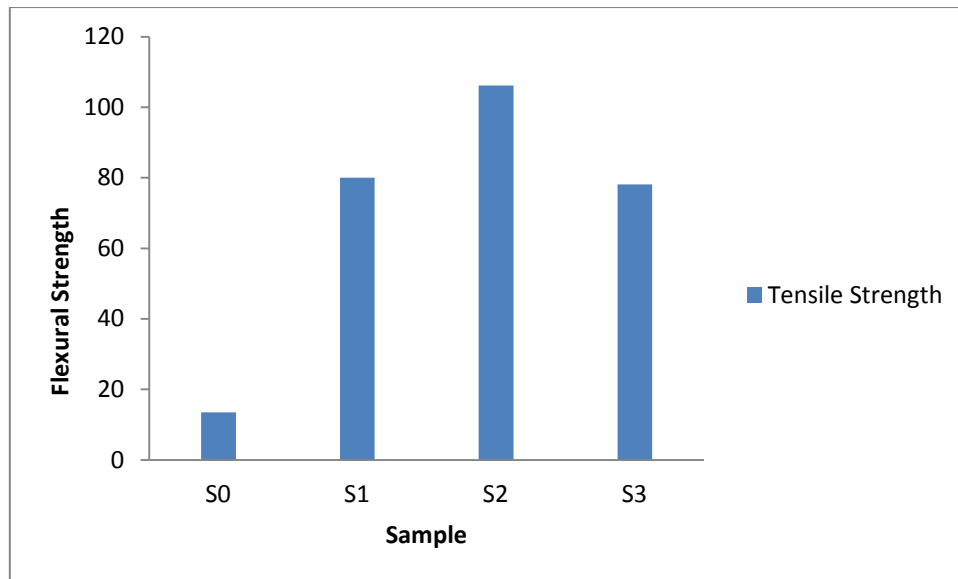


Figure-3.12 Variation of tensile strength with different layers of treated *Luffa Cylindrica* fibre epoxy composites exposed to distil water environment.

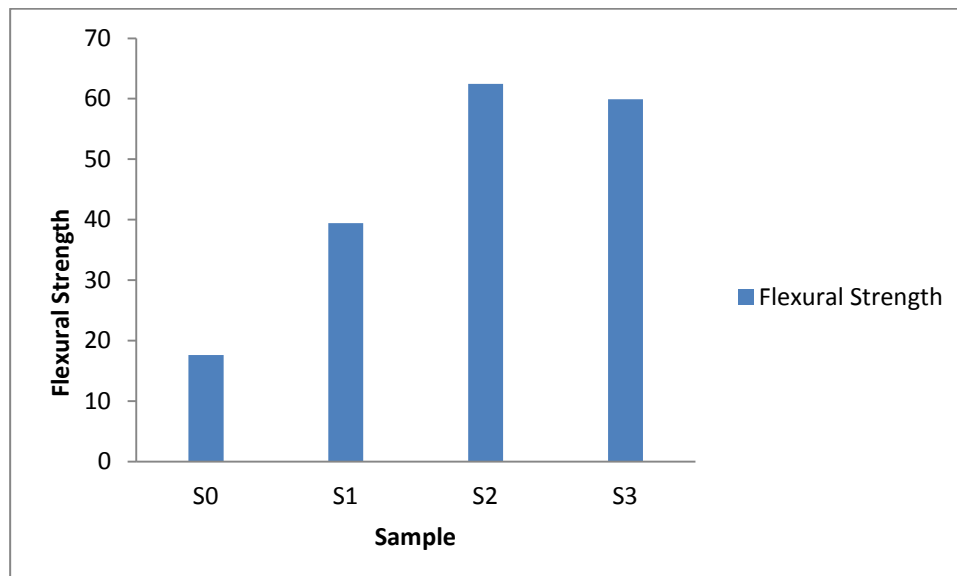


Figure-3.13 Variation of flexural strength with different layers of treated *Luffa Cylindrica* fibre epoxy composites exposed to distil water environment.

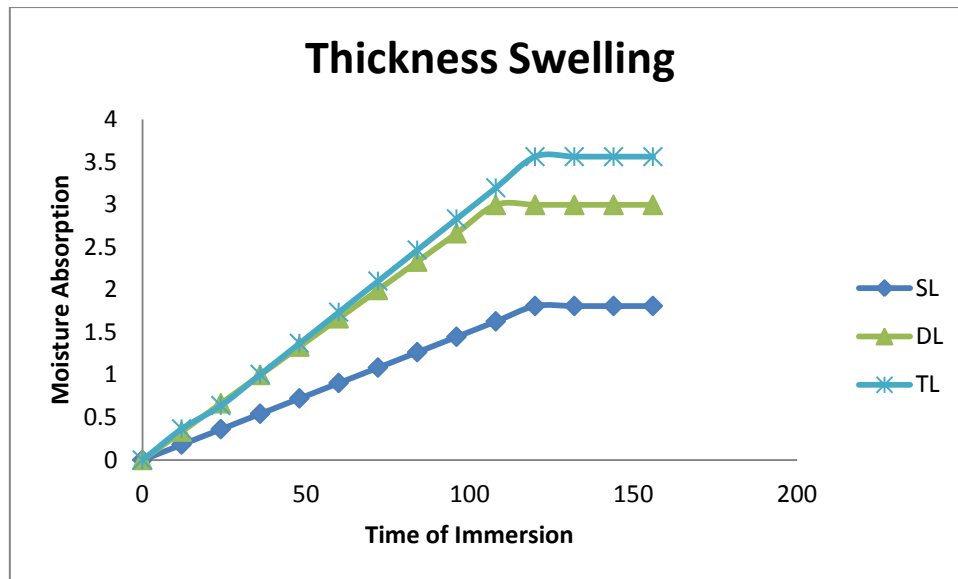


Figure-3.14 Variation of thickness swelling of untreated Luffa Cylindrica fibre epoxy composites (tensile) with immersion time at saline water environment.

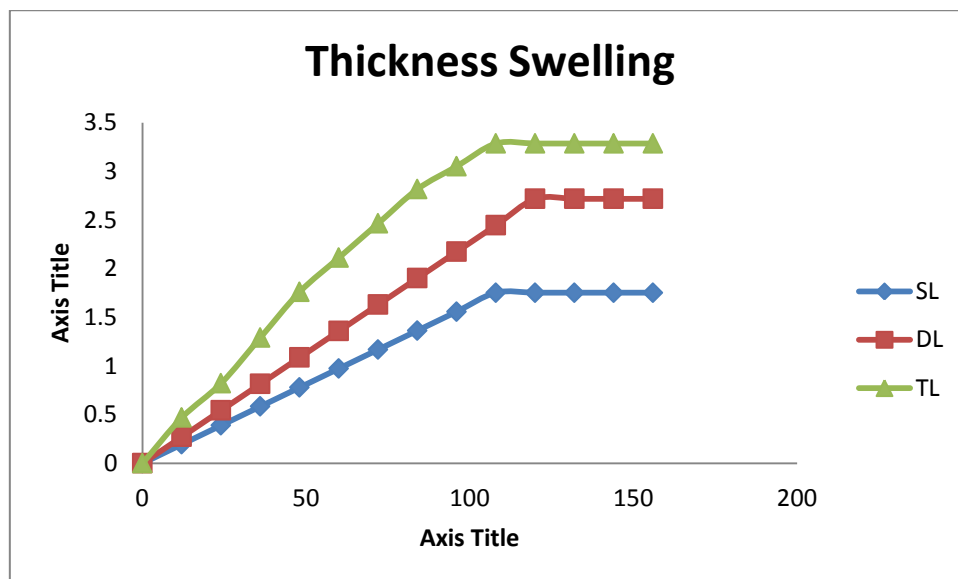


Figure-3.15 Variation of thickness swelling of treated Luffa Cylindrica fibre epoxy composites (tensile) with immersion time at saline water environment.

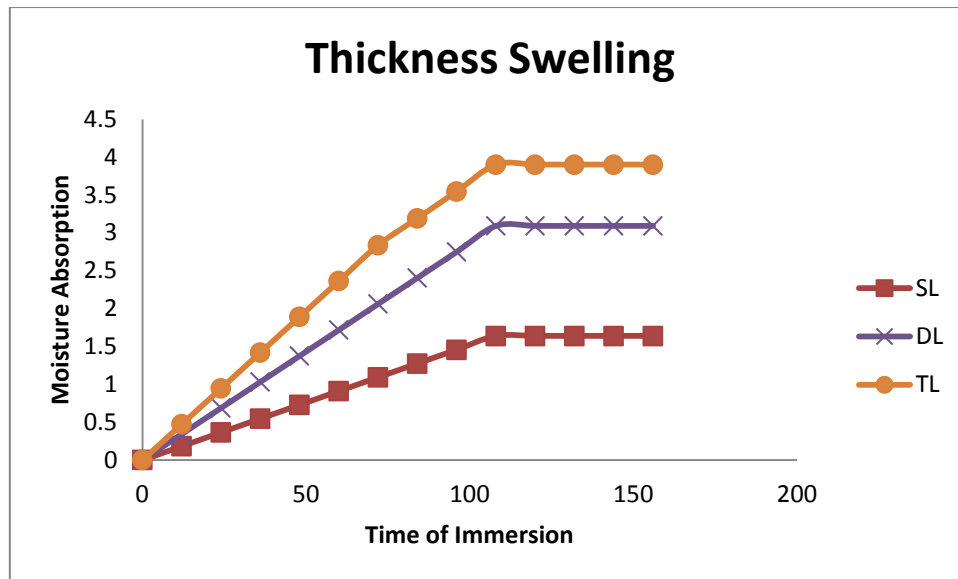


Figure-3.16 Variation of thickness swelling of untreated Luffa Cylindrica fibre epoxy composites (flexural) with immersion time at saline water environment.

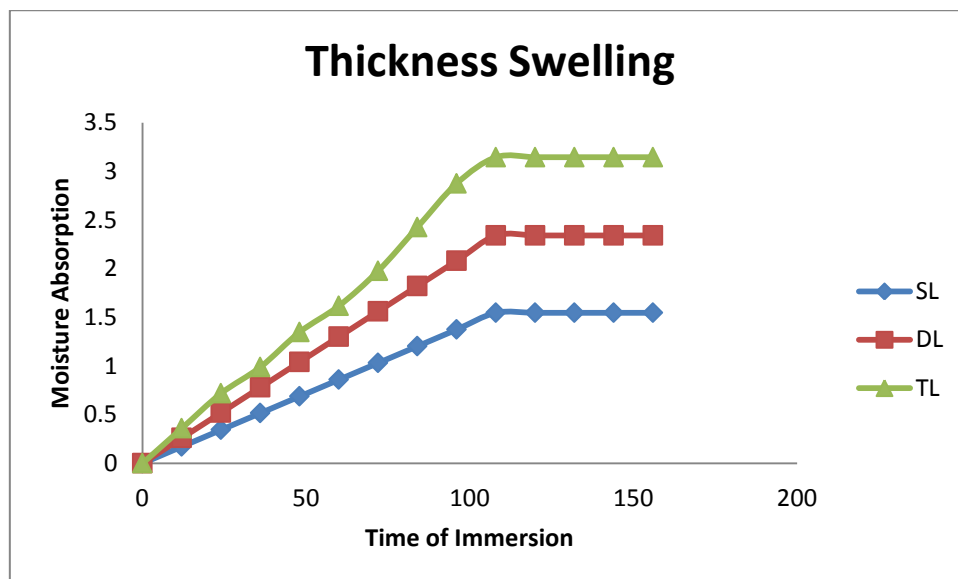


Figure-3.17 Variation of thickness swelling of treated Luffa Cylindrica fibre epoxy composites (flexural) with immersion time at saline water environment.

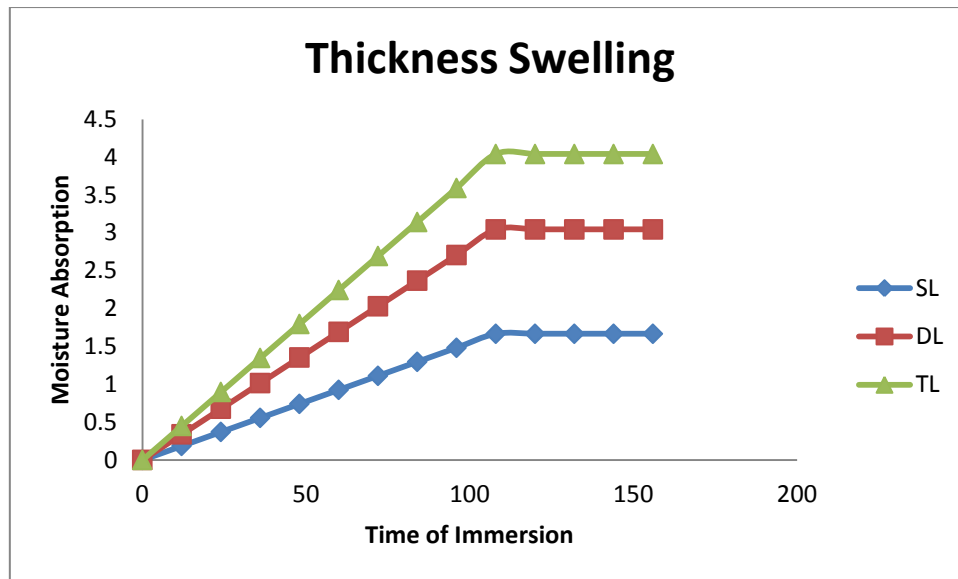


Figure-3.18 Variation of thickness swelling of untreated Luffa Cylindrica fibre epoxy composites (tensile) with immersion time at distil water environment.

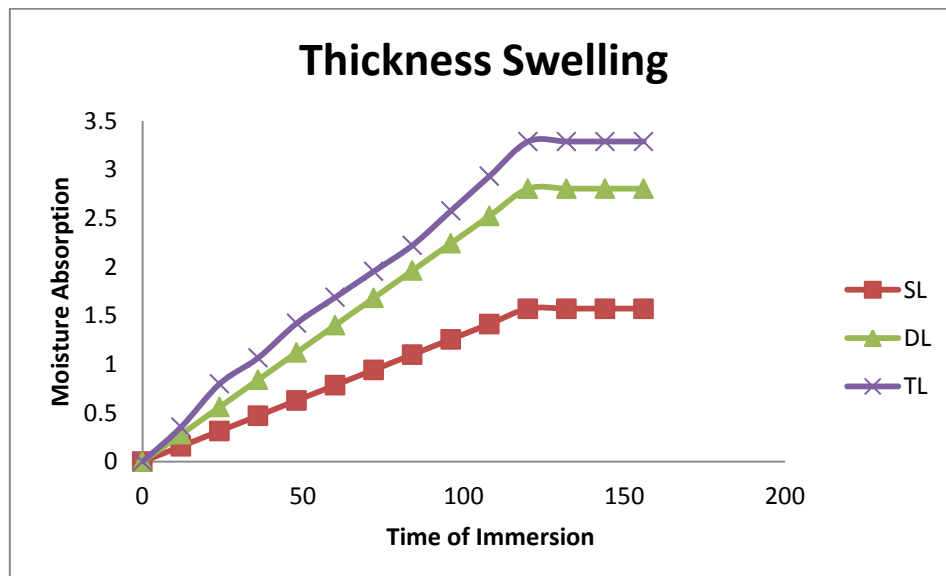


Figure-3.19 Variation of thickness swelling of treated Luffa Cylindrica fibre epoxy composites (tensile) with immersion time at distil water environment.

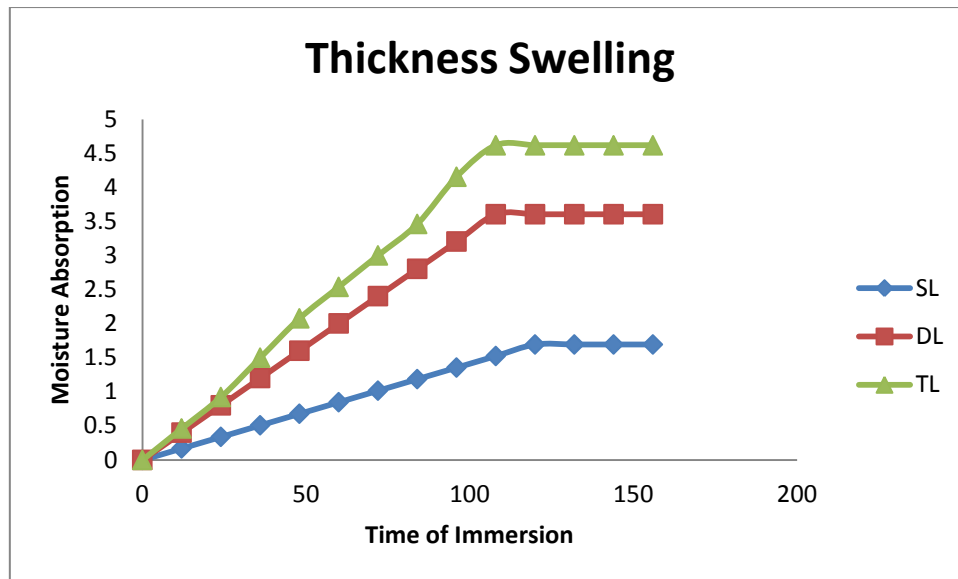


Figure-3.20 Variation of thickness swelling of untreated Luffa Cylindrica fibre epoxy composites (flexural) with immersion time at distil water environment.

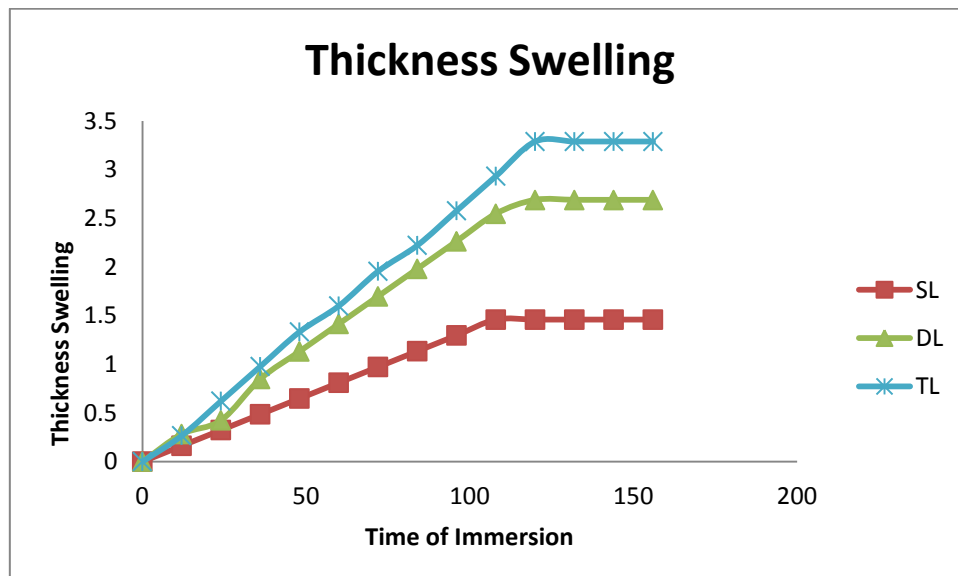


Figure-3.21 Variation of thickness swelling of treated Luffa Cylindrica fibre epoxy composites (flexural) with immersion time at distil water environment.

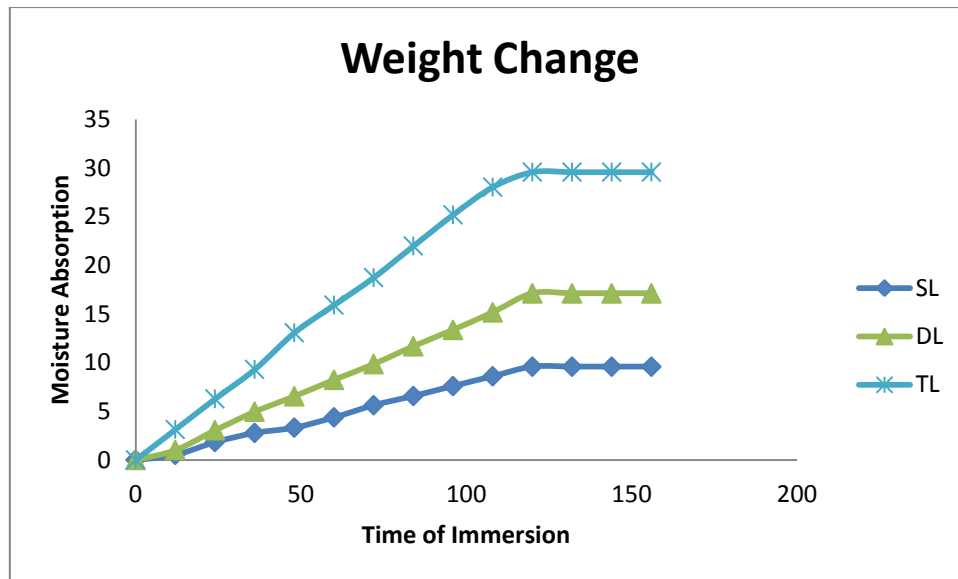


Figure-3.22 Variation of weight gain of the untreated *Luffa Cylindrica* fibre epoxy composites (tensile) with immersion time at saline water environment.

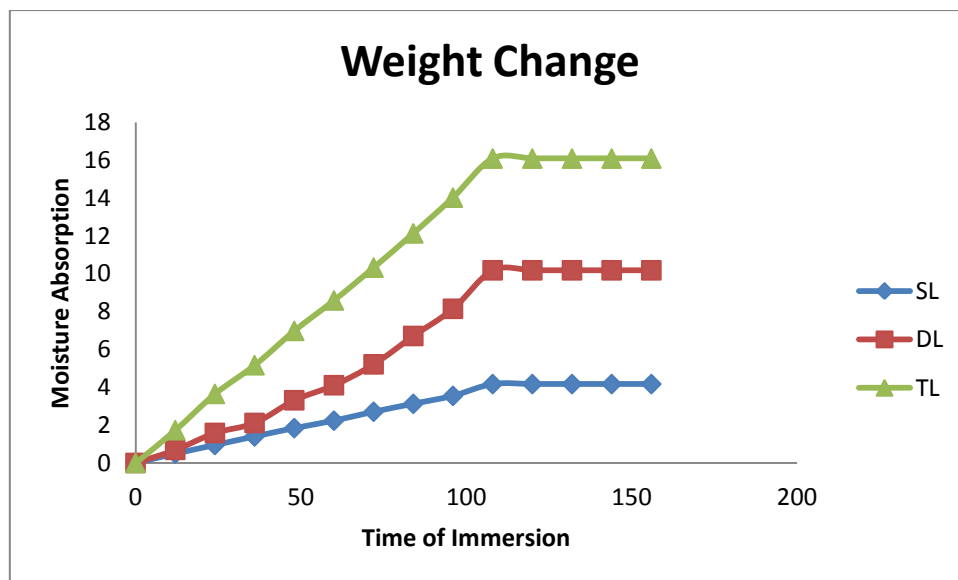


Figure-3.23 Variation of weight gain of the treated *Luffa Cylindrica* fibre epoxy composites (tensile) with immersion time at saline water environment.

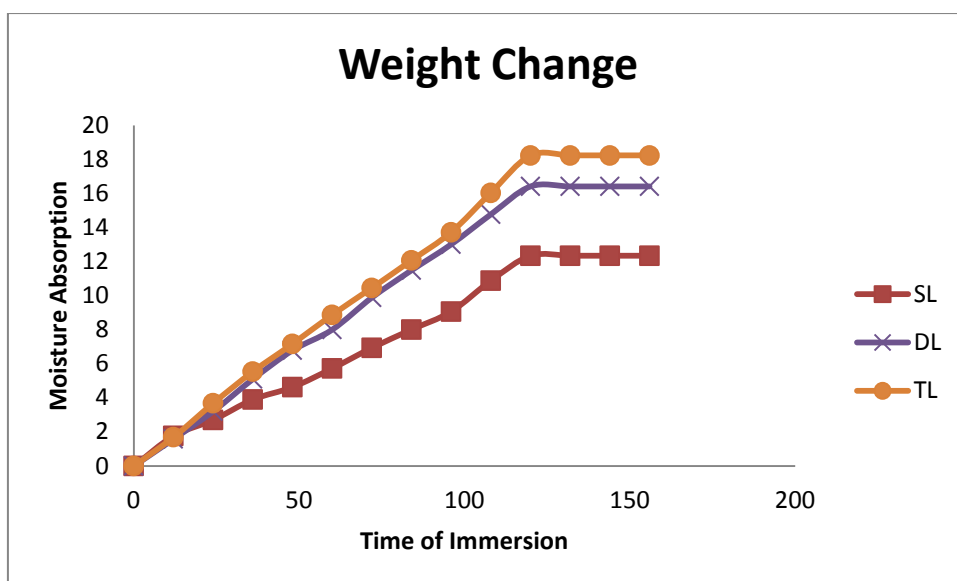


Figure-3.24 Variation of weight gain of the untreated Luffa Cylindrica fibre epoxy composites (flexural) with immersion time at saline water environment.

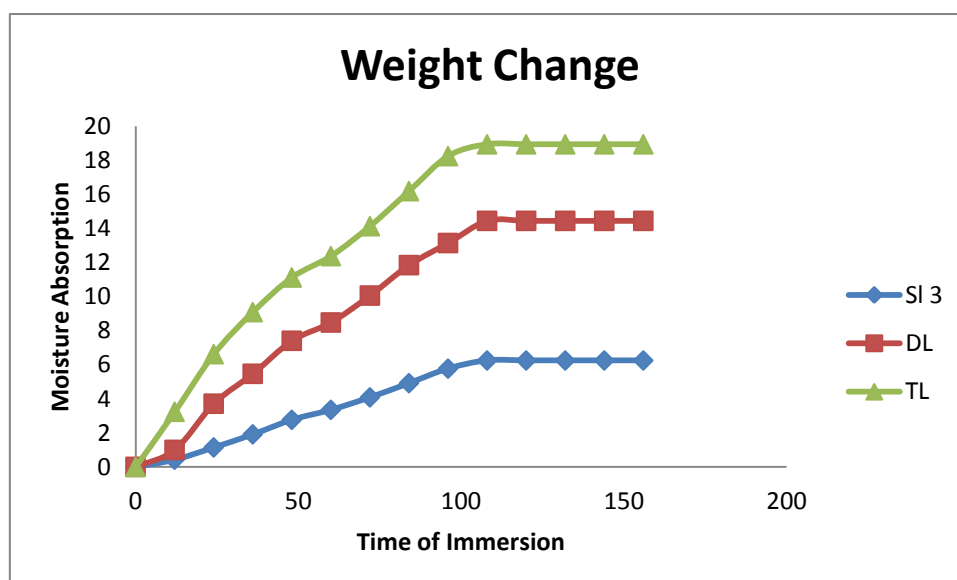


Figure-3.25 Variation of weight gain of the treated Luffa Cylindrica fibre epoxy composites (flexural) with immersion time at saline water environment.

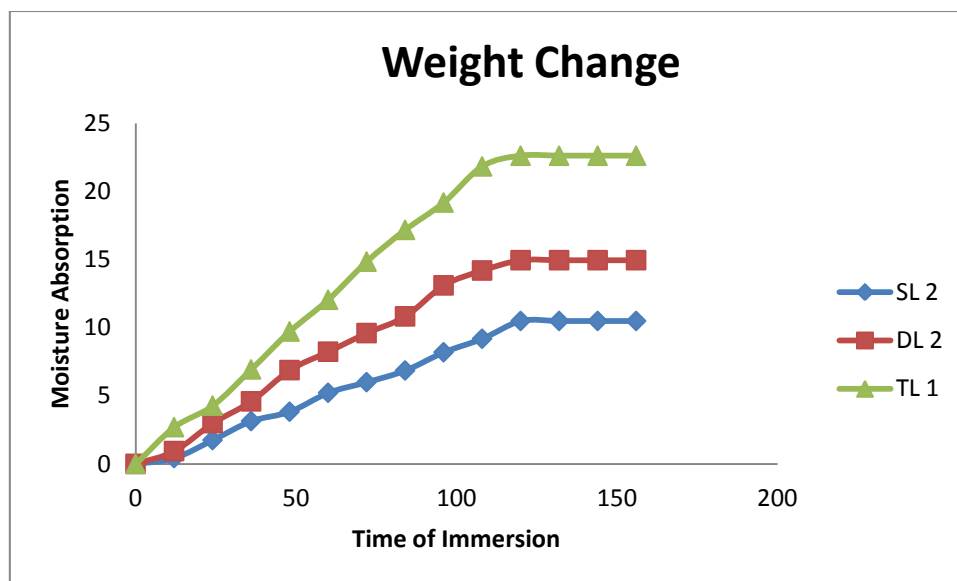


Figure-3.26 Variation of weight gain of the untreated Luffa Cylindrica fibre epoxy composites (tensile) with immersion time at distil water environment.

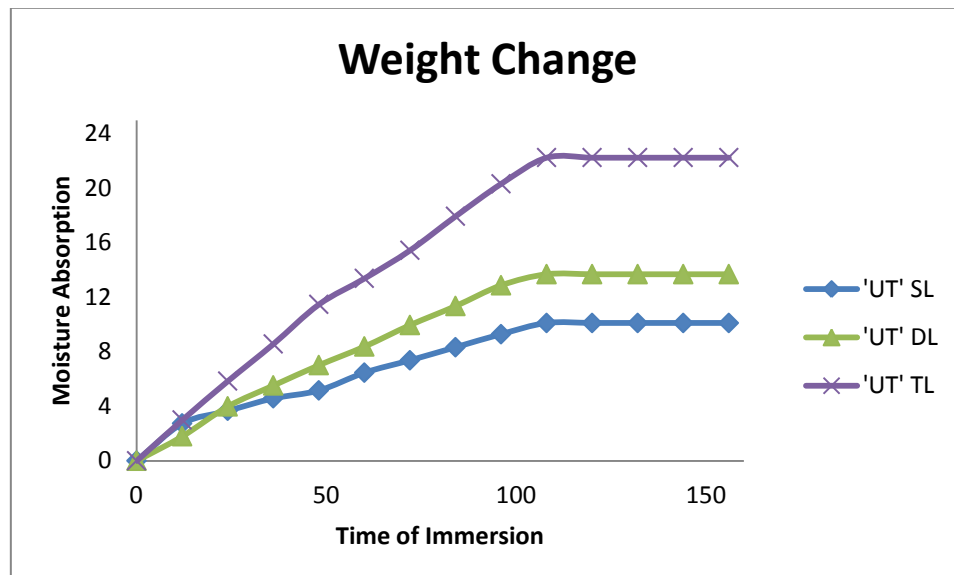


Figure-3.27 Variation of weight gain of the treated Luffa Cylindrica fibre epoxy composites (tensile) with immersion time at distil water environment.

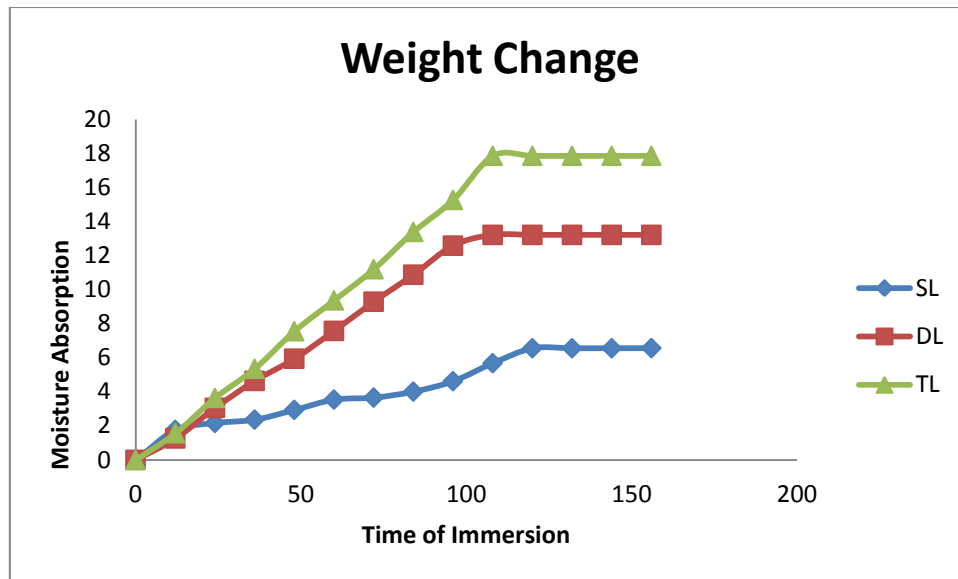


Figure-3.28 Variation of weight gain of the untreated *Luffa Cylindrica* fibre epoxy composites (flexural) with immersion time at distil water environment.

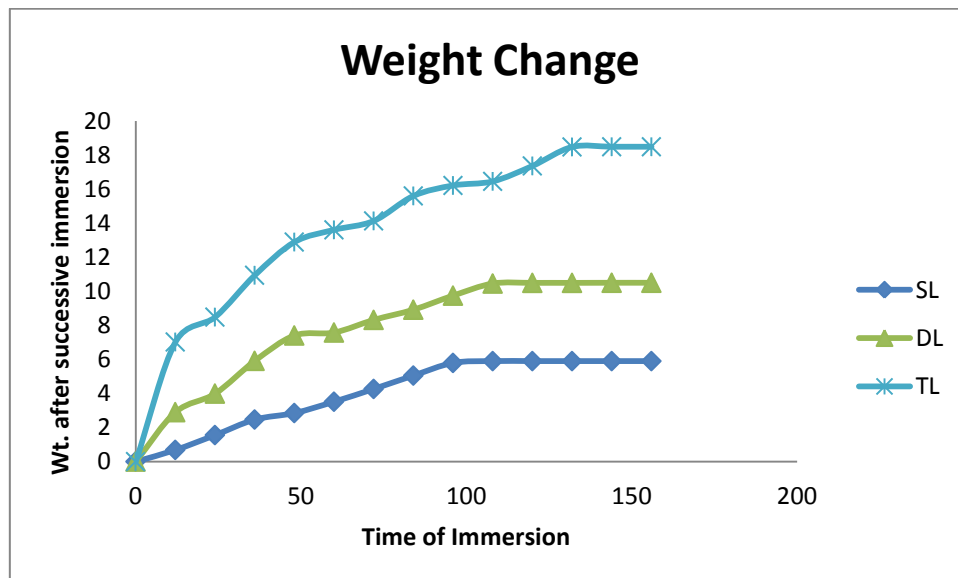


Figure-3.29 Variation of weight gain of the treated *Luffa Cylindrica* fibre epoxy composites (flexural) with immersion time at distil water environment.

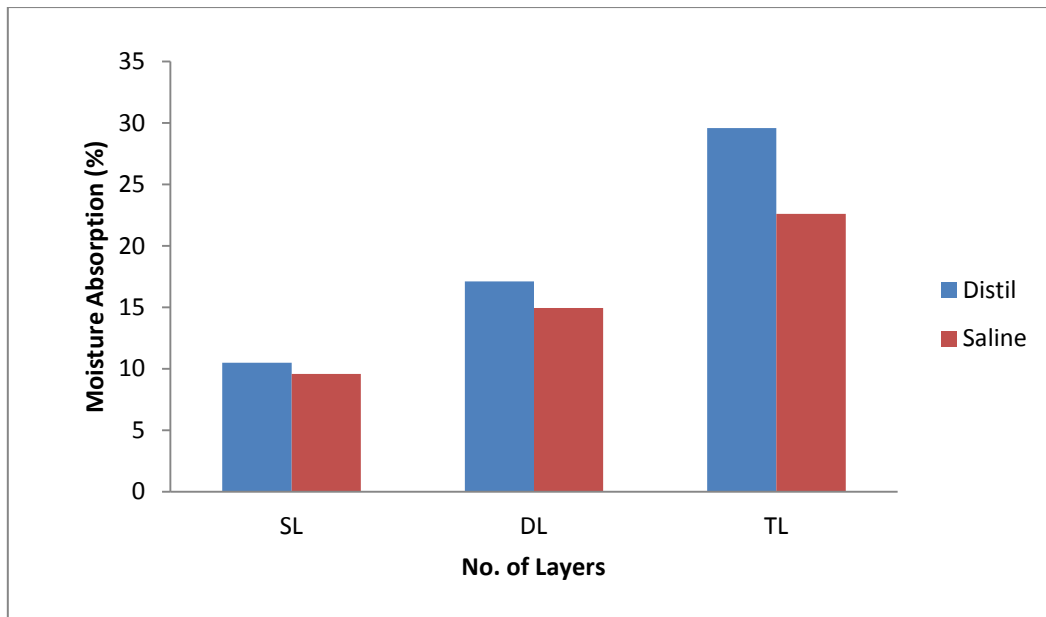


Figure-3.30 Maximum moisture absorption of untreated Luffa cylindrica fiber epoxy composite (tensile samples) versus fiber loading in both the environments

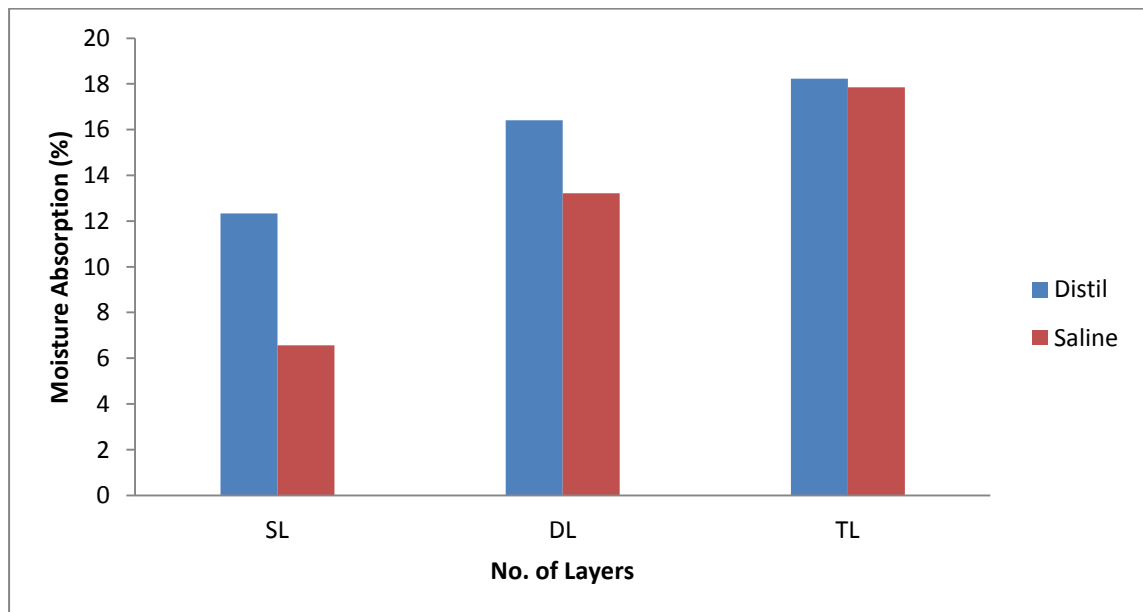


Figure-3.31 Maximum moisture absorption of untreated Luffa cylindrica fiber epoxy composite (flexural samples) versus fiber loading in both the environments

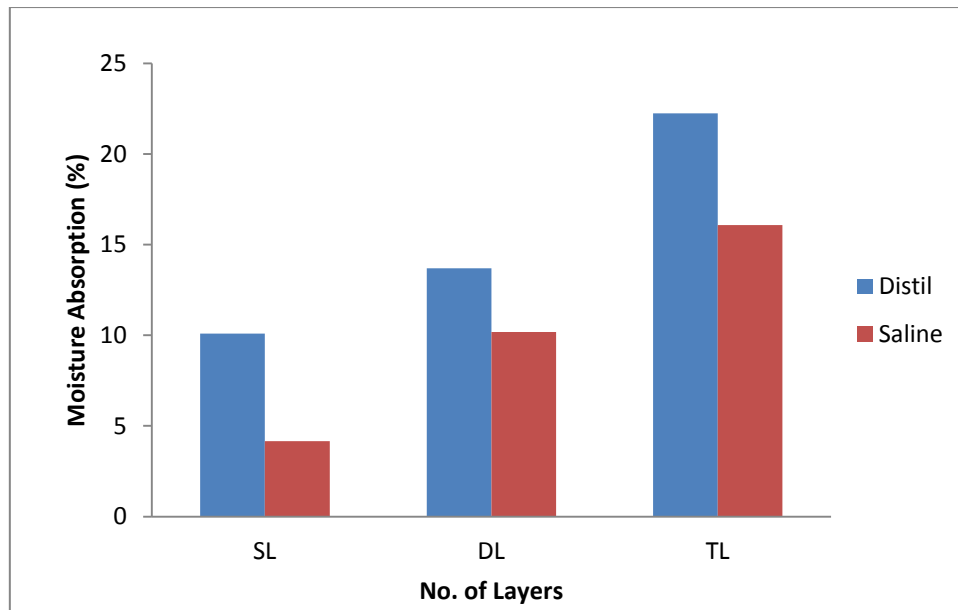


Figure-3.32 Maximum moisture absorption of treated Luffa Cylindrica fiber epoxy composite (tensile samples) versus fiber loading in both the environments

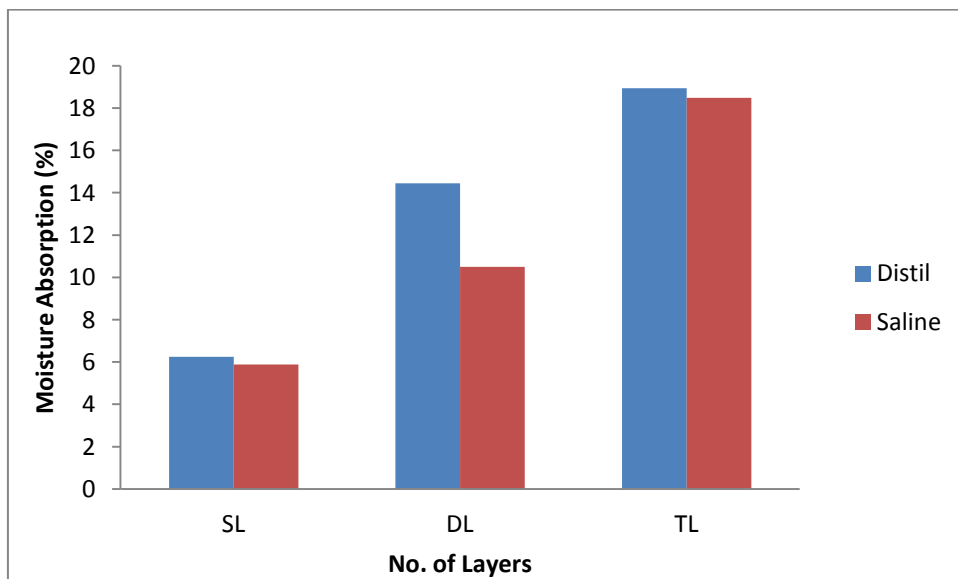


Figure-3.33 Maximum moisture absorption of treated Luffa Cylindrica fiber epoxy composite (flexural samples) versus fiber loading in both the environments

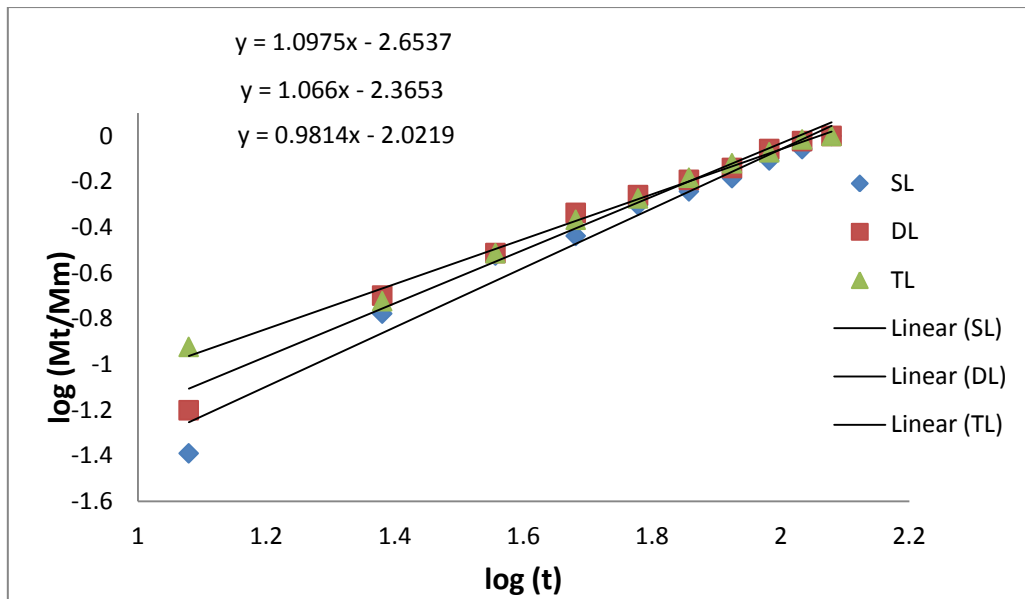


Figure-3.34 Example Diffusion curve fitting for Luffa Cylindrica fiber epoxy composites under Different environments

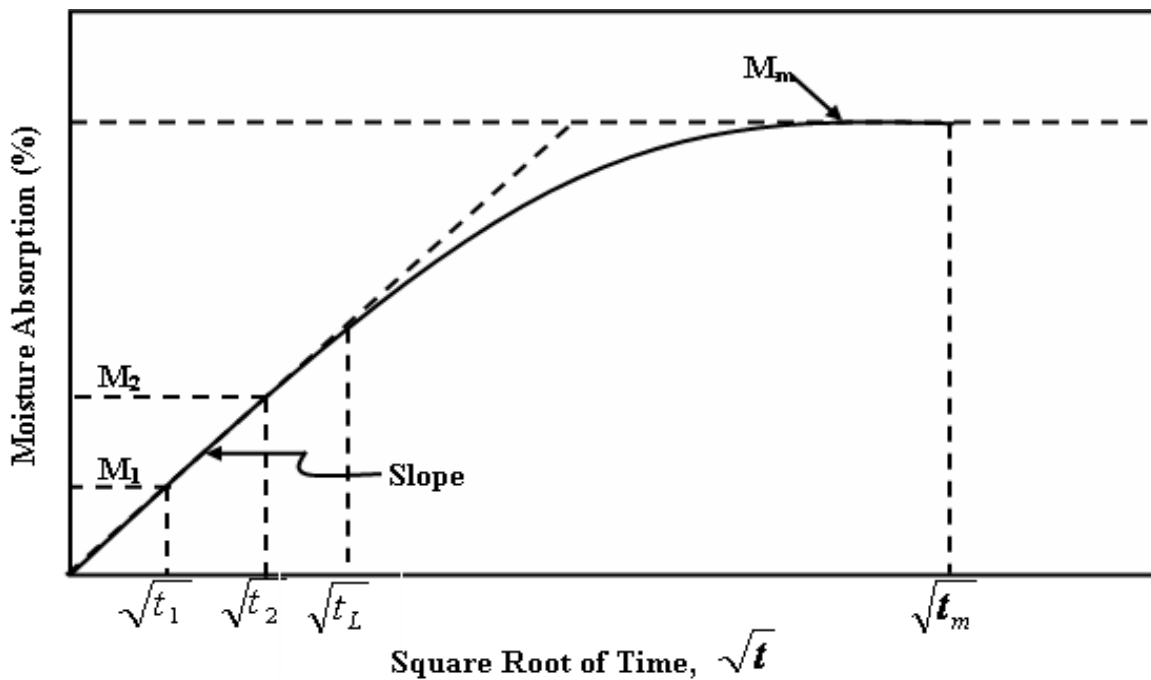


Figure-3.35 Example Plot of percentage of moisture absorption versus square root of time for calculation of Difusivity

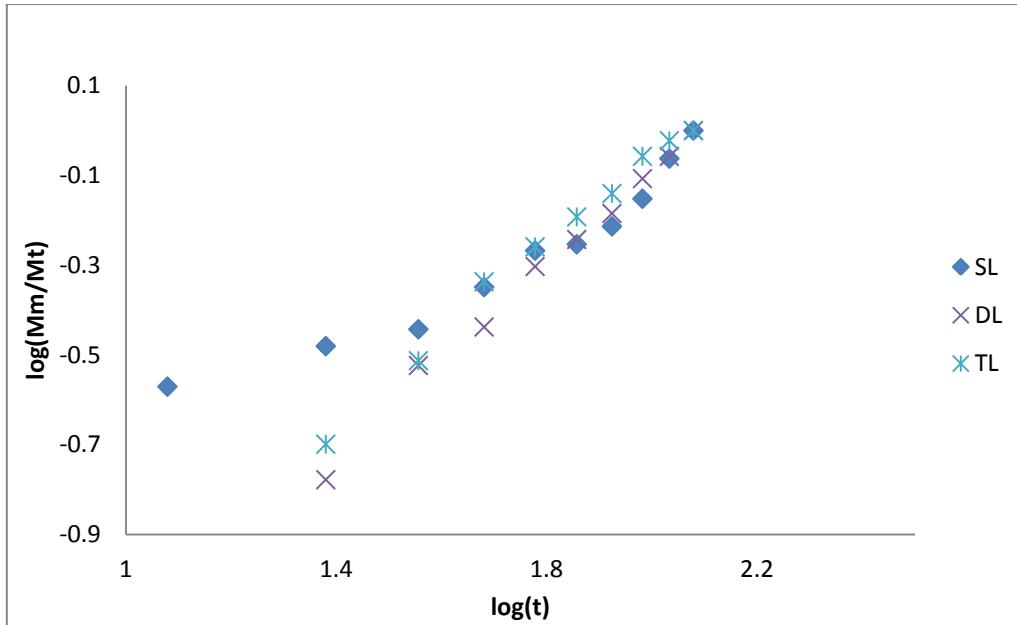


Figure-3.36 Variation of $\log (M_t/M_m)$ with $\log (t)$ for untreated Luffa Cylindrica fiber epoxy composites (flexural) at distil water environment

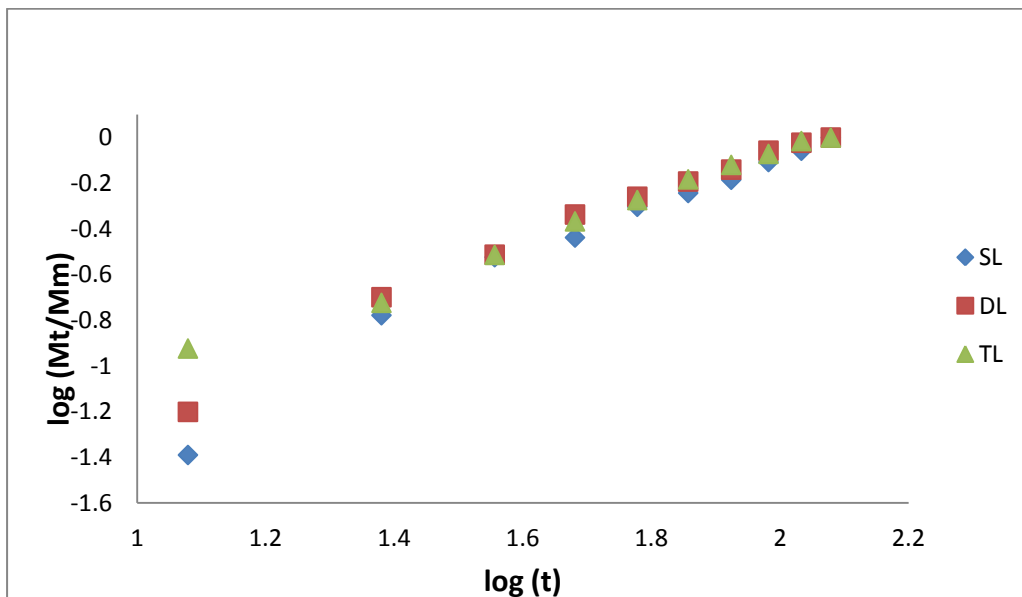


Figure-3.37 Variation of $\log (M_t/M_m)$ with $\log (t)$ for untreated Luffa Cylindrica fiber epoxy composites (tensile) at distil water environment

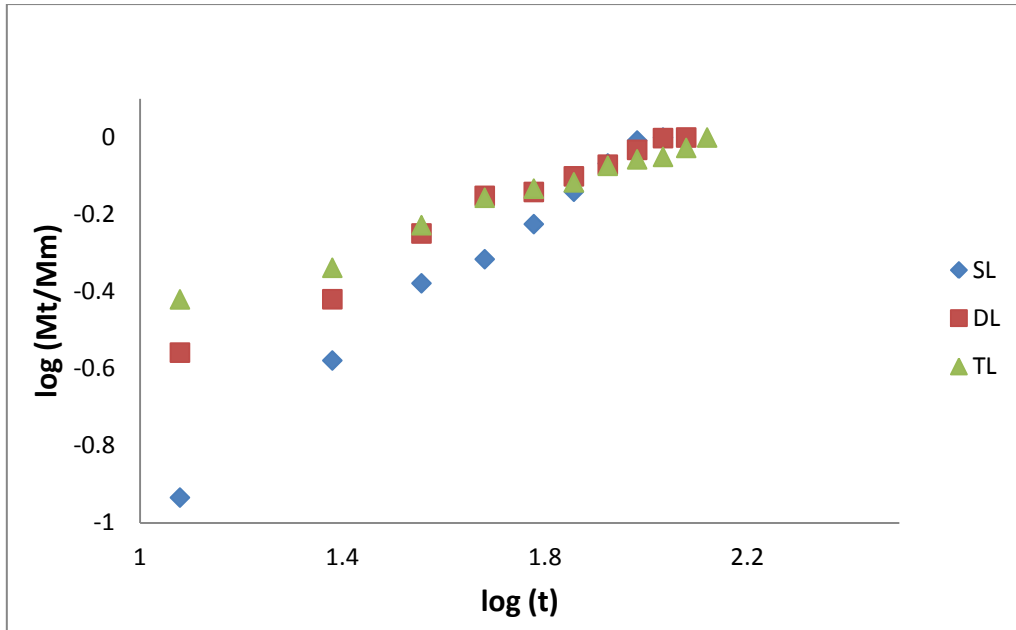


Figure-3.38 Variation of $\log (M_t/M_m)$ with $\log (t)$ for treated Luffa Cylindrica fiber epoxy composites (flexural) at distil water environment

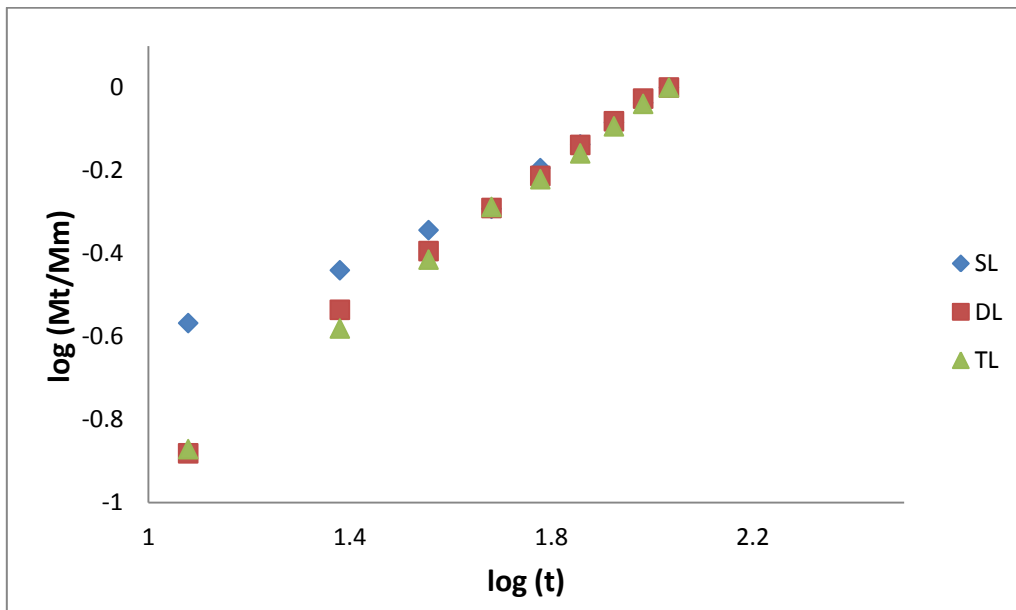


Figure-3.39 Variation of $\log (M_t/M_m)$ with $\log (t)$ for treated Luffa Cylindrica fiber epoxy composites (tensile) at distil water environment

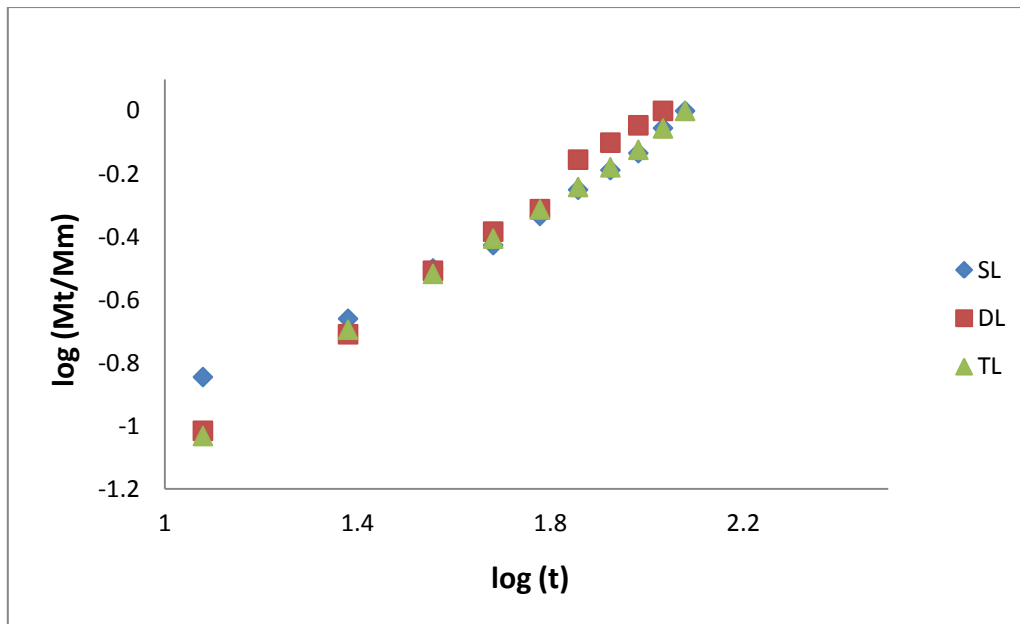


Figure-3.40 Variation of $\log (M_t/M_m)$ with $\log (t)$ for untreated Luffa Cylandrica fiber epoxy composites (flexural) at saline water environment

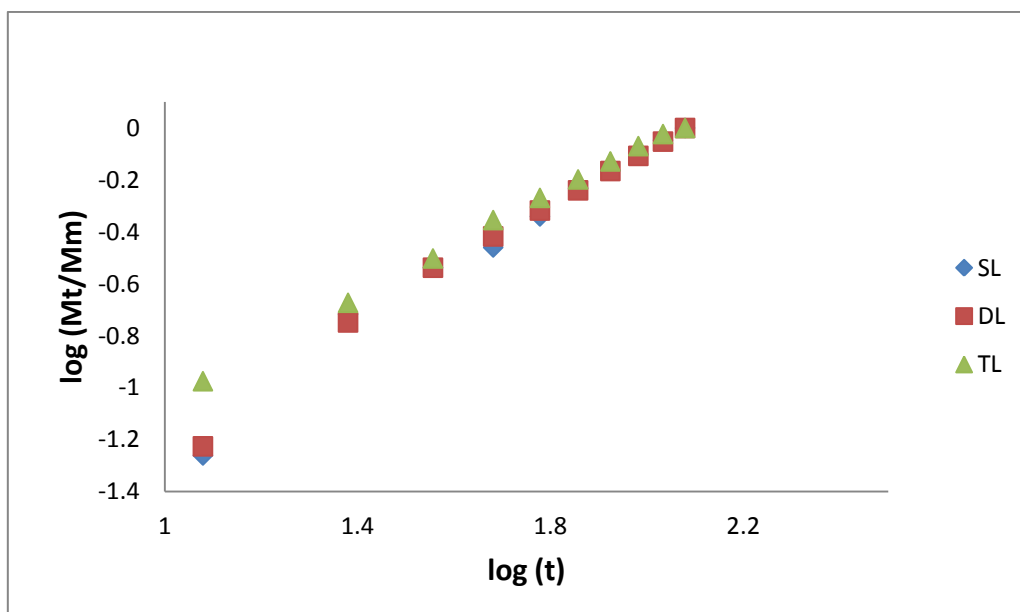


Figure-3.41 Variation of $\log (M_t/M_m)$ with $\log (t)$ for untreated Luffa Cylandrica fiber epoxy composites (tensile) at saline water environment

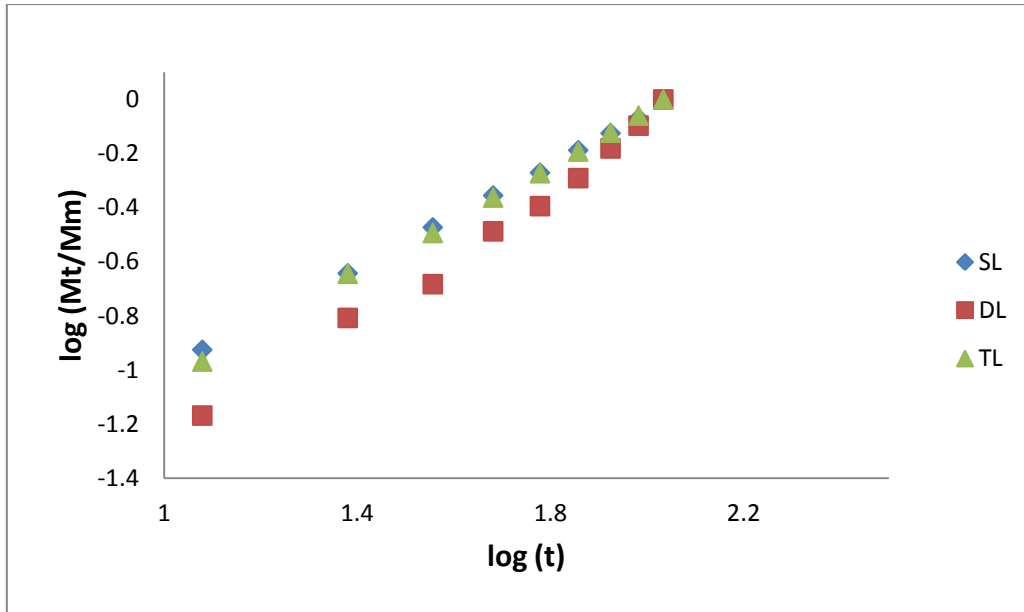


Figure-3.42 Variation of $\log (M_t/M_m)$ with $\log (t)$ for treated Luffa Cylindrica fiber epoxy composites (tensile) at saline water environment

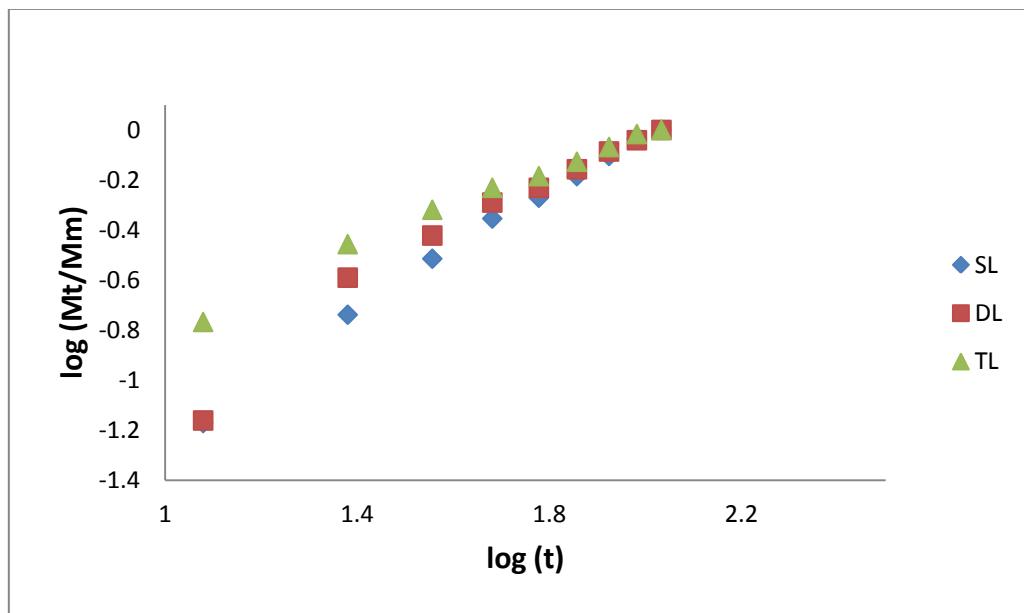


Figure-3.43 Variation of $\log (M_t/M_m)$ with $\log (t)$ for treated Luffa Cylindrica fiber epoxy composites (flexural) at saline water environment

Chapter 4

REFERENCES

4. REFERENCES

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